

Human and Robotic Technology (H&RT)

Advanced Space Technology Program
Technology Maturation Program
Innovative Technology Transfer Partnerships Program

Formulation Plan

Version 5.1
29 July 2004 (Amended 13 September 2004)



Development Programs Division
Office of Exploration Systems
National Aeronautics and Space Administration
Washington, D.C. 20546

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**Human and Robotic Technology (H&RT)
Formulation Plan**

Advanced Space Technology Program
Technology Maturation Program
Innovative Technology Transfer Partnerships Program

Approved by¹:



14 May 2004

Deputy Director for H&RT
Development Programs Division
Office of Exploration Systems

Date

Updates and Revisions:

This H&RT Formulation Plan will be updated and/or revised as may be appropriate during the course of its implementation, subject to the same approvals as the initial document. Comments on this edition are welcome; please provide any inputs to john.c.mankins@nasa.gov.

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¹ This Formulation Plan for H&RT Programs is released with the concurrence of the Director, Development Programs Division, Office of Exploration Systems, NASA.

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Section 1

Introduction

1.1 Background

On January 14, 2004 President Bush established a new policy and strategic direction for the U.S. civil space program—establishing human and robotic space exploration as it’s primary goal, and setting clear and challenging goals and objectives. In response to this charge, the National Aeronautics and Space Administration (NASA) created a new Office of Exploration Systems (OExS) at the Agency’s headquarters and created or realigned several major programmatic budget themes.

1.2 Strategic Framework

The new ‘vision for space exploration’ at the beginning of 2004 encompasses a broad range of human and robotic missions, including the Moon, Mars and destinations beyond. It establishes clear goals and objectives, but sets equally clear budgetary ‘boundaries’ by stating firm priorities, including ‘tough choices’ regarding current major Agency programs. The new vision establishes as policy the goals of pursuing commercial and international collaboration in realizing future space exploration missions. Also, the policy envisions that advances in human and robotic technology will play a key role—both as enabling and as a major benefit of the new vision.²

In particular, the Space Exploration Vision states that the fundamental goal of Vision is **“to advance U.S. scientific, security and economic interests through a robust space exploration program.”** In pursuit of this goal, the Vision states that in support of this goal, the U.S. will pursue four key objectives; these are to:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and,
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests

² Appendix C provides details concerning the ‘strategy-to-task’ linkages from the updated NASA Strategic Goals and Objectives and the several outcomes and annual performance goals (APGs) relevant to Human and Robotic Technology.

1.3 H&RT Goals and Objectives

Goals: The investments made through the Human and Robotic Technology (H&RT) programs will provide the critical foundation of knowledge and validated technologies for achieving the Vision for Space Exploration, while delivering technologies of broad common value to NASA, the Nation and the U.S. economy.

Objectives: Accomplishing this goal will entail the following principal objectives (in approximately order of priority).

- Establish the viability (or non-viability) of various major systems and systems-of-systems options for longer-term future exploration systems, with a focus in the next 6-9 years on the systems-of-systems level issues that will determine how we return to the Moon by no later than 2020.
- Address on a priority basis any critical gaps in needed capabilities and/or technologies that emerge during definition of the systems that OExS will ‘build next’—for example, in the near term, H&RT will address capability gaps that may exist for “Spiral 1” (leading to the 2014 first flight of the CEV with crew).
- Develop, demonstrate and deliver component-, subsystem-, or system-level technologies for consideration by system developers that may provide an alternative chosen technologies and provide a substantial improvement in key aspects of systems-level characteristics. This will be a lower priority within H&RT, to be addressed as appropriate and possible given competing demands for funds.
- Develop, demonstrate and transfer technologies of broad common value, for NASA missions, other government applications and for the benefit of the economy.
- Assure the timely creation and effective management of innovative research and technology development and transfer partnerships to accomplish better NASA’s exploration, science and technology goals.

The Exploration Vision states: “preparing for exploration and research accelerates the development of technologies that are important to the economy and national security. The space missions in this plan require advanced systems and capabilities that will accelerate the development of many critical technologies.” Primary responsibility for organizing, implementing and coordinating diverse activities in response to the new Exploration Vision—with a particular focus on the development of new technologies and systems—rests with the recently-created Office of Exploration Systems.³

³ Details of the new policy may be found in the “Vision for Space Exploration” document (see Reference in Appendix B).

1.4 Organizational Context

The Office of Exploration Systems comprises three major organizations: (1) a Business Operations Division, which will manage acquisition strategy and process, as well as OExS budgetary, legislative and outreach activities; (2) a Requirements Development Division, which will frame the high-level requirements for future exploration systems to be developed; and, (3) a Development Programs Division, which is responsible for the formulation and management of the new NASA exploration budget themes: Project Constellation (a.k.a., the Transportation Systems Theme), which will be responsible for new exploration systems development (e.g., the crew exploration vehicle (CEV)); and the Human and Robotic Technology (H&RT) Theme.

The Human and Robotic Technology (H&RT) Theme synthesizes several major ongoing programs along with new program content and directions, as well as numerous personnel into a novel endeavor that will make a critical contribution to the new U.S. Space Exploration Vision. The H&RT Theme comprises the following programs:

- Centennial Challenges. An experimental approach to stimulating innovation and competition in technical areas of interest to NASA.
- Project Prometheus. A major investment to develop new building block capabilities in the area of space nuclear reactor power and propulsion systems.
- Advanced Space Technology. Formerly the Mission and Science Measurement Technology (MSMT) program; it provides the broad, low TRL-foundation for much of NASA space technology.
- Technology Maturation. A new program to develop and validate novel systems concepts and high-leverage technologies to enable safe, affordable, effective and sustainable human and robotic exploration, while filling critical gaps in nearer-term capabilities.
- Innovative Technology Transfer Partnerships. A collection of programs that includes NASA's Small Business Innovation Research (SBIR) program; it seeks to enable the creative use of intellectual assets both inside and outside NASA to meet Agency needs and to benefit the Nation.

1.5 Scope

During the FY 2004, the new H&RT Theme will be organized, incorporating both new and ongoing programs. This document is the Formulation Plan for the following programs within the H&RT Theme: the Advanced Space Technology Program (ASTP), the Technology Maturation Program (TMP), and the Innovative Technology Transfer Partnerships (ITTP) Program.

This document does not encompass FY 2004 program formulation efforts related to the remaining two programs within the NASA Human and Robotic Technology Theme: Project Prometheus (the nuclear systems program) or the new Centennial Challenges program.

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Section 2

Formulation Plan Goals and Objectives

The following section details the several goals and objectives of this H&RT Programs Formulation Plan.

2.1 Goals

The goals of this Plan are to assure that

- (1) Formulation efforts for the involved H&RT programs are completed successfully and on schedule;
- (2) Reformulation results in an integrated 'strategy-to-task-to-technology' (STT) approach for all affected ongoing technology programs (i.e., that they successfully achieve their goals, objectives, and outcomes) and immediate annual performance goals (APGs) within the context of national policy and Agency strategic planning;⁴ and,
- (3) Consistent with above goals, that formulation results in the minimum dislocation of individual personnel who may be affected while providing for the highest-quality staffing in support of the future program.

2.2 Objectives

In order to accomplish these goals, this Plan comprises five objectives:

- Establishing a Set of New Management Processes. Setting into place new organizational and technology management processes that can better assure the timely accomplishment of H&RT objectives and outcomes. These processes will enable better integration with the Exploration Vision major milestones, application of strategy-to-task-to-technology (STT) investment portfolio definition, use of Earned Value Management Systems (EVMS), and others.
- Establishing an H&RT Team. Establishing a highly competent, well-integrated team for H&RT both at NASA Headquarters and across the NASA Field Centers.
- Program Formulation / Re-formulation and Coordination. Integrating and aligning appropriate ongoing space technology and research programs with new H&RT technology R&D (e.g., within the new Technology Maturation Program).
- Project Selection, Implementation and Coordination. Establishing new processes and exercising them in the competitive selection of H&RT technology projects, and the more-effective execution of those projects once selected.

⁴ Per the January 14, 2004, Space Exploration Vision, the NASA Strategic Plan it is being re-formulated.

- Assuring the Timeliness of Formulation Accomplishments. Rapidly and effectively achieve these objectives in support of the President's FY'05 budget, and planning for the FY'06 budget and out years.

The following sections detail the approach and describe key elements of the plan.

Section 3

Program Formulation Approach

3.1 Overview

The effort to formulate the relevant H&RT programs will be undertaken as an integral part of other Office of Exploration Systems planning and programs. The approach used in this Formulation Plan involves three phases leading within six months to the creation of the initial H&RT organization, establishment of an integrated new management approach encompassing all relevant aspects of the new program, and guidance to—and planning responses from—the participating NASA Field Centers in preparation for FY 2005 program implementation and FY 2006 (and out-year) program planning. The three planned phases are the following:

- Establishing a new work breakdown structure (WBS) for H&RT, initiating the NASA Program Operating Plan (POP) cycle based on that WBS, and developing this H&RT Programs Formulation Plan.
- Creating a new H&RT program management structure involving NASA-wide teams under NASA Headquarters leadership, and formulating new program plans in all affected areas of H&RT, consistent with the Exploration Vision and the management processes/plans for OExS. This topic is discussed in more detail in Section 7.
- Establishing and executing competitive processes for the competitive formulation of both extramural R&D (through a Broad Agency Announcement (BAA)) and intramural R&D (through a competitive process to be finalized, but similar in character to a focused NRA). This topic is discussed in more detail in Section 7.

3.2 Affected Programs

Several programs, both ongoing and new, are affected by the planned program formulation (and re-formulation) effort during FY 2004. These include three former Office of Aerospace Technology (Code R) programs:

- The Mission and Science Measurement Technology (MSMT) Theme, with its three programs (CICT, ECT and ECS)⁵, and
- The Innovative Technology Transfer Partnerships (ITTP) Program, with its three elements (SBIR, STTR and the Technology Transfer network)⁶.

In the new H&RT Theme, MSMT has been redefined as a more focused new program, the Advanced Space Technology Program (ASTP). In addition, the former Office of

⁵ These are Computing, Information and Communications Technology (CICT), Enabling Concepts and Technology (ECT), and Engineering for Complex Systems (ECS).

⁶ These are Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR).

Space Flight (Code M) Advanced Systems Program has been transferred to the Office of Exploration Systems and incorporated into a new effort, the Technology Maturation Program (TMP).

3.3 Program Operating Plan (POP) Guidelines

On 16 March 2004, the Office of Exploration Systems (OExS) and the Office of the NASA Comptroller (Code B) issued Program Operating Plan (POP) Guidelines for the Office of Exploration Systems, including Human and Robotic Technology (H&RT). (The H&RT-relevant portion of these guidelines is provided in Appendix D).

3.4 Coordination with Other Enterprises

Another aspect of the Formulation Plan will be the identification of a clear and consistent set of relationships with the closely related programs across the several NASA Enterprises. The Enterprises with which H&RT must be coordinated include the Office of Space Science, Office of Space Flight, the Office of Biological and Physical Research, and others. In each case, there will be both common and unique aspects to the coordination process.

For example, within the NASA Office of Biological and Physical Research (OBPR; or “Code U”), there will be investments related to the ‘human as subsystem’ in future space missions. The relevant technologies may include areas such as regenerative life support, extravehicular activity (EVA) systems, and others. The Plan anticipates the development and approval of a Memorandum of Agreement (MOA) between Code T and Code U by the end of the period addressed by the Plan. (This is a secondary objective; details are not shown in this version of the Plan, but will be added following consultation with Code U in a later update of the Plan.)

3.5 Coordination with Other Agencies

In addition, during the next several months, a series of working discussions with other U.S. Government Agencies will be held to set the stage for future coordination and potential collaboration outside of NASA.

Section 4

Strategic R&D Model for Human and Robotic Technology

The following section provides an overview of the ‘strategic model for research and development (R&D) that will be used in formulating the H&RT investment portfolio.

4.1 Focused Process for Technology Development

The formulation process for H&RT programs will be guided by a coherent concept of how the process of space technology research, development and maturation occurs for space exploration.⁷ The foundation of this approach, as illustrated in Figure 4-1, is the technology readiness levels (TRLs). The central concept of the “TRLs” is that the maturation (current and future) of a particular technology may be characterized in a discipline-independent fashion (subject to the assessment of third-parties).

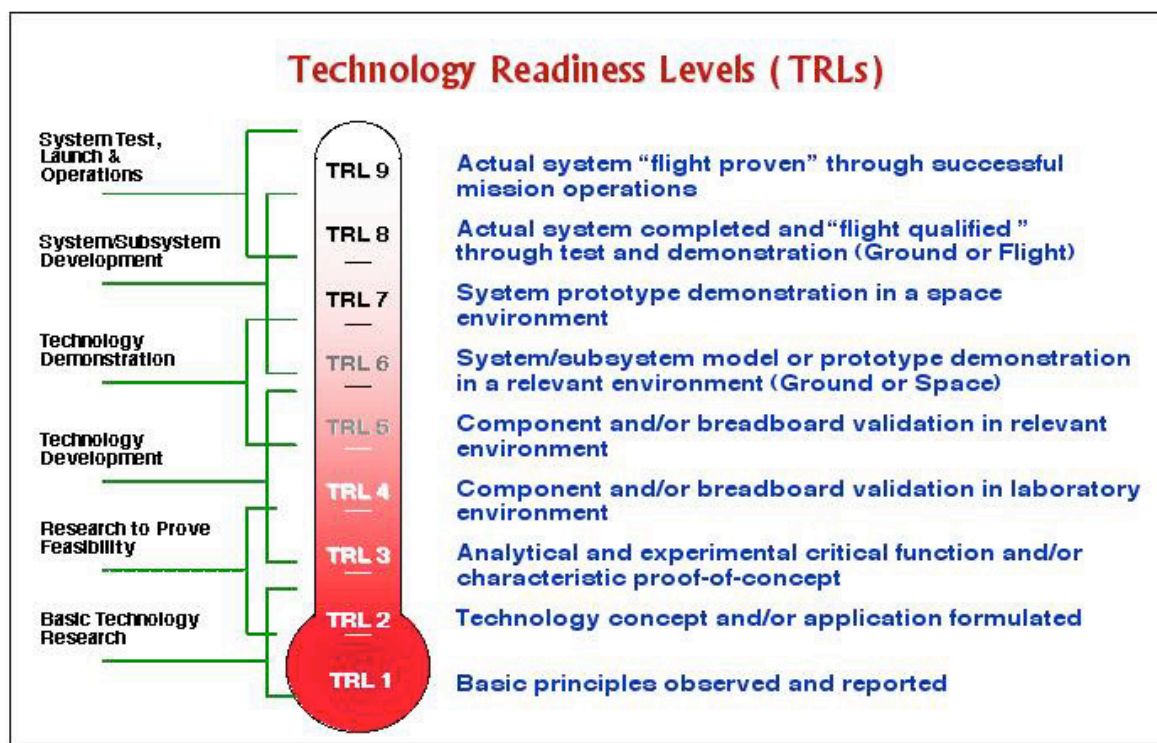


Figure 4-1 Space Technology Maturation Process: Technology Readiness Levels.

⁷ This model of how technologies and systems are advanced is admittedly idealized; the intention is only to create a framework for H&RT planning—including establishing processes for the competitive selection of technology projects.

On the basis of the TRLs, it is possible to frame a typical process/programmatic flow for technology development. The standard model that will be assumed for H&RT planning is depicted in Figure 4-2. The beginnings of technology research are found in fundamental research (TRL 1); these lead, with the conception of a way to apply some new phenomena or analytical insight to the beginnings of technology (TRL 2). The resulting ‘flow’ continues with TRL 2 through 5.

There are five distinct steps in the strategic knowledge/technology/systems development model that is assumed within H&RT. The first of these (up to TRL 1) is ‘basic research’; these are programs the purpose of which is to better understand the world around us. Such research programs provide the basis for the second step, ‘supporting advanced space technology research’; this step involves programs that begin with a concept (TRL 2) and lead to the validation of a component and/or breadboard in the laboratory. (There have long been programs of this kind within NASA and other agencies.)

The next phase is a critical aspect of the H&RT investment approach: a focused investment in ‘technology maturation’ that results in the demonstration of technologies at the systems level in a relevant environment. The fourth step in this strategic model are the actual ‘system development projects and programs’ that result in new systems. The final step is the implement of flight mission projects.

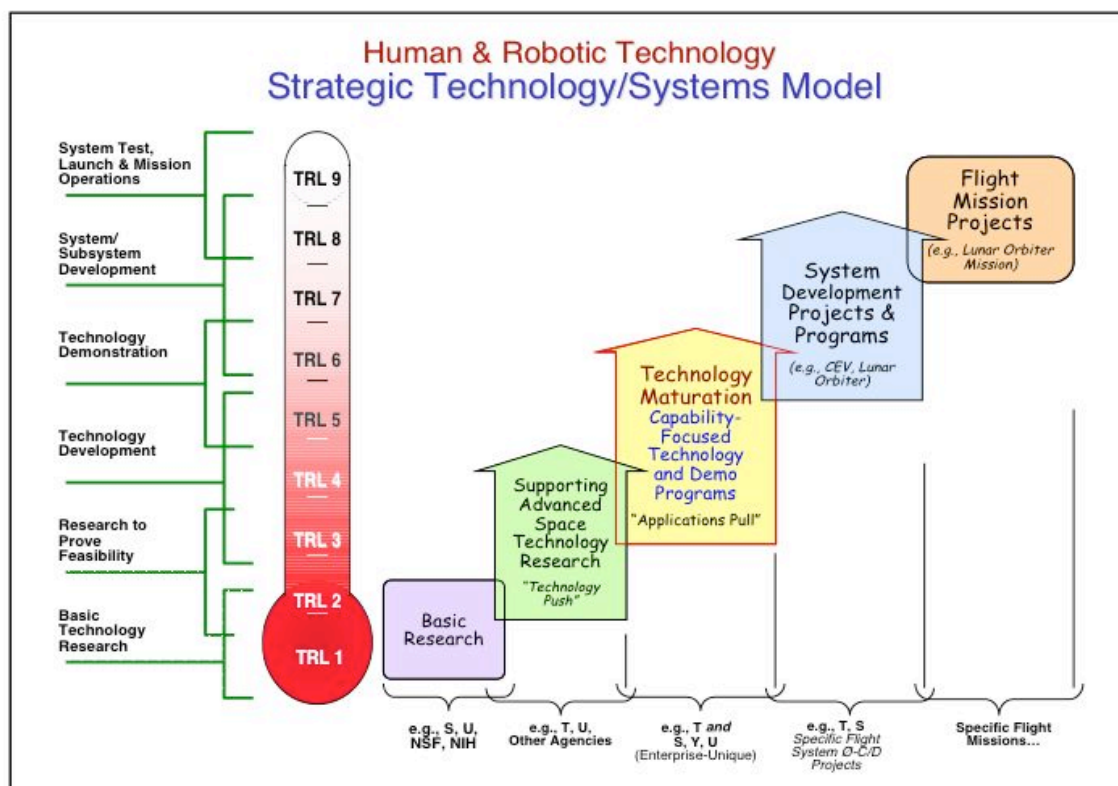


Figure 4-2 Space Technology Maturation Process: Programmatic “Flow”

It is also important to note that in this model of for exploration technology that knowledge, technology and missions (at each step) may be achieved by various organizations (See Figure 4-2), including several NASA Enterprises, other U.S. government Agencies, and others.

4.2 Competitive Approach to Portfolio Selection/Evolution

The schedule on which advances are achieved in critical new space technologies and resulting systems-level capabilities is extremely important to the success of the Vision for Space Exploration. Although it is highly difficult to anticipate the precise schedule by which a specific technology will mature, nevertheless there are very effective portfolio-based approaches that may be employed to better assure that the overall goals and objectives of the program will be achieved.⁸

The Human and Robotic Technology programs comprising this investment will be formulated to pursue precisely such a strategy for focused, schedule-driven and competition-enabled technology development. Figure 4-3 illustrates an integrated, competitive approach for Human and Robotic Technology portfolio selection (and evolution).

The central features represented in this competitive approach to project selection and program evolution are:

- (1) Initial consideration at low TRLs of multiple technological approaches to solve the same problem, for example, within the Advanced Space Technology Program (ASTP); followed by a down-selection based on progress (and improved understanding of goals and objectives for future systems). The starting point for this phase is TRL 2 or 3 (with a goal of TRL 3 or 4, depending on the starting point and the specifics of the technology being developed).
- (2) The second phase for ASTP is the continuing consideration at intermediate TRLs of a reduced number of technological approaches to solve the same problem(s) as the initial phase. The goal of this phase is TRL 5. This phase is also the key transition step from ASTP to the Technology Maturation Program (TMP). This phase involves two down-selection processes: first, within ASTP in selecting technologies to take to TRL 5, and later (if needed) within TMP in selecting a refreshed set of candidate technologies to be matured—but, now integrated into a more realistic, systems-level setting (perhaps a prototype or test bed).

⁸ In simple terms, the concept is to investment in multiple developments of technology each of which are targeted on the same challenge. Note that the approach may be either parallel or serial. For example, in the case of Thomas A. Edison and the invention of the incandescent bulb, a variety of alternative approaches and/or filament materials were investigated serially—until a successfully candidate emerged. In another example, the parallel investment approach was used to very good effect by the Manhattan District Project in the development of the atomic bomb during World War II. Because of the schedule-constrained character of the Exploration Vision, H&RT will pursue a parallel technology R&D approach, consistent with availability of funds.

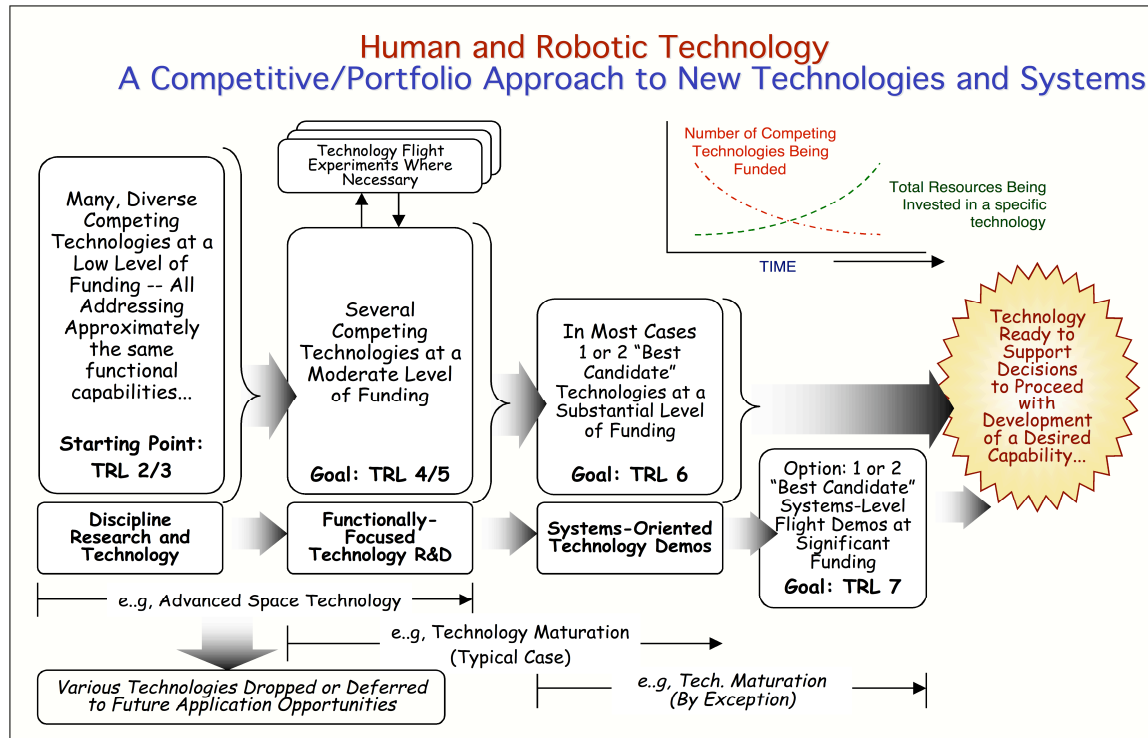


Figure 4-3 Competitive Approach to Project Selection and Program evolution

- (3) Next, and typically last, is a phase in which the TMP completes the validation at TRL 6 (i.e., a system or subsystem model or prototype validated in a relevant environment”) of a handful (perhaps as few as 1-2 technologies) candidates.

Figure 4-4 summarizes the new conceptual set of relationships between ASTP TMP—and adds both ITTP and other external programs/projects such as exploration systems development projects (e.g., Project Constellation).

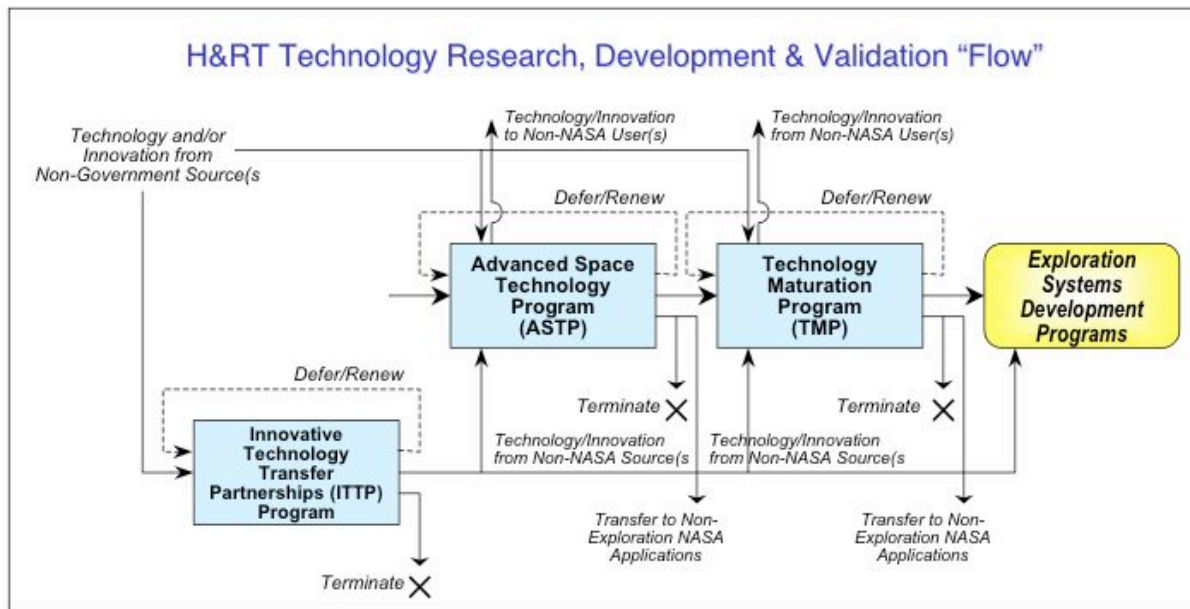


Figure 4-4 Conceptual "Flow" of Technology through H&RT Programs

The Defense Advanced Research Projects Agency (DARPA) provides a highly useful model for the technology portfolio management approach being considered here. A key concept within the Defense Advanced Research Projects Agency (DARPA) is that of 'exit criteria' for each project undertaken. (See the Reference from L. Dubois.) These criteria are defined in order to allow more effective and timely future decisions about when a technology is 'ready' for transition. A part of the concept is to identify clearly prospective applications for a given technology, and to formulate at the beginning of the project just what would comprise sufficient data to allow a decision to be made as to whether to use the technology in the application.

4.3 Strategy-Driven Technology Planning

A coherent, 'strategy-to-task-to-technology' (STT) approach to the H&RT Theme will be crucial to ultimate success of the Agency's exploration goals and objectives. This process will incorporate long-standing practices such as the use of technology readiness levels (TRLs), and extend them with more recently developed space technology management tools and techniques. The use of technology assessment and analysis tools will be pursued, including application of the ATLAS ("Advanced Technology Life-cycle Analysis System") methodology and tools including discipline-independent technology management metrics such as the R&D3 (Research and Development Degree of Difficulty) and methods such as the ITAM (Integrated Technology Analysis Methodology).

In addition, during its first year of operations an important OExS deliverable will be an integrated "investment plan" based on the WBS gap analysis. The initial 'gap analysis' will be implemented by the OExS Requirement Division with the support of the H&RT team during FY 2004, with inputs from the planned Request for Information (RFI), also described as a 'Broad Area Announcement' (BAA) and support from

industry. These efforts will result in inputs to H&RT planning for technologies with potential impact at both the “system-of-systems” level, as well as the “subsystem level.”

There will be additional process-related products, including memoranda of agreement (MOAs), inputs to the development of the planned H&RT Integrated Technology Plan (ITP; by September 2004), and others. The central processes of H&RT management, including coordination with ongoing exploration systems developments, will be documented in a series of ISO-compliant Office Work Instructions (OWIs).

The task of establishing a true strategic-to-task-to-technology (STT) approach for human and robotic technology will not be completed during FY 2004. Efforts will also continue during FY 2005. As indicated in the NASA FY 2005 Performance Plan, Annual Performance Goal (APG) 4HRT3, identifies the intention to charter a ‘technology transition team’ that will review candidate human/robotic exploration systems technologies and provide detailed updates to human/robotic technology road maps. (See Appendix C.) Within H&RT this role will be played by the team created via the 2004 program formulation process (which has been established by this Formulation Plan).

4.4 Process-Related Products

In summary, major process-related Formulation Plan products will include:

- An overarching H&RT ‘integrated technology plan’, consistent with program responsibilities, goals and objectives, and program content;
- An integrated family of internally consistent ISO 9001 Office Work Instructions for the H&RT Programs, embodying an end-to-end STT approach.

Section 5

Cycles of Innovation and Spiral Development of Systems

The following section discusses the relationships between the planned exploration systems ‘spiral development’ strategy and the supporting ‘cycles of innovation’ that will be planned as the foundation for developing H&RT program (and later project) schedules.

5.1 Spiral Development and Exploration Systems

The systems needed to achieve the new U.S. Vision for Space Exploration will be developed over many years and by diverse organizations. With the NASA Office of Exploration Systems, a focused family of new systems will be developed that represent critical “building block capabilities” for future human and robotic space exploration. These systems will be developed using a ‘spiral development’ approach, adapted from a process of strategic systems management first applied within the U.S. Department of Defense (DOD).

Within spiral development for space exploration, initial systems will be framed in the context of a broad vision of future missions and systems, but without attempting to define in precise detail the specifications or designs for systems that will not enter into full-scale development for years or decades into the future. Instead, long-term program goals and objectives will be established (i.e., “level zero” requirements) and a range of candidate ‘concepts of operations’ (ConOps) identified, along with various options for future systems and technologies (at least through the mid term). These options will be identified in the context of QFD (quality function deployment) and related management processes to drive out the key functional capabilities that would enable truly transformation systems-of-systems level innovations to emerge in the future.

The spiral development process and plan—as well as ‘level zero’ requirements—will be defined in support of the schedule of major milestones established in the Vision for Space Exploration. (See additional discussion below.) This new development approach will begin with the development of the Crew Exploration Vehicle (CEV), a critical first system within Project Constellation.

From the ‘level zero’ requirements, more detailed ‘level one’ requirements for nearer-term systems will be framed, and used as the basis to begin major systems acquisition processes, including procurements, systems analysis and design studies, and later development, testing and deployment. Throughout, highly competitive acquisition processes will be used, including regular competitive project events (e.g., ‘fly-offs’) among competing candidate concepts and vendors. For example, within Project Constellation the Development Programs Division (Code TD) within OExS will pursue the definition and development, working with industry of no fewer than two CEV test vehicles for flight by 2008.

Technology development planning and specific technology projects will be formulated in response to the anticipated course of spiral development, with the following three major goals:

- Establish the viability (or non-viability) of various major systems and systems-of-systems options for longer-term future exploration systems, with the focus in the next 6-9 years on the systems-of-systems level issues that will determine how we return to the Moon by no later than 2020. This will be the major focus of the H&RT investment portfolio.
- Address on a priority basis any critical gaps in needed capabilities and/or technologies that emerge during definition of the systems that OExS will ‘build next’—for example, in the near term, H&RT will address capability gaps that may exist for the 2014 first flight of the CEV with crew. This will be second major focus on the H&RT investment portfolio.
- Develop, demonstrate and deliver component-, subsystem-, or system-level technologies for consideration by system developers that may provide an alternative chosen technologies and provide a substantial improvement in key aspects of systems-level characteristics. This will be a lower priority within H&RT, to be addressed as appropriate and possible given competing demands for funds.

These technology development plans will, of course, need to be reformulated as systems development and testing is completed, as R&D progresses and in the context of evolving goals and objectives for space exploration. Figure 5-1 provides a summary view. Appendix J provides a more detailed forecast of potential events and activities associated with the long-term implementation of the National Vision for Space Exploration. (This forecast should be used as a reference in identifying the candidate applications for H&RT technology programs and projects.)

5.2 H&RT Projects and Other NASA Enterprise Technology Needs

In addition, Human and Robotic Technology efforts will provide an important foundation for broadly applicable new technologies for use in future systems developed by various NASA Enterprises. In supporting the new National Space Exploration Vision, NASA plans some adjustments in this important investment area. Historically, the MSMT program sought to address a variety of science and instrument specific technologies (and the name, “Mission and Science Measurement Technology” suggests), as well as technologies with broader (e.g., subsystem level) implications.

As a result of this H&RT formulation effort, OExS will refocus the ongoing ASTP (formerly MSMT) and the new TMP toward two types of technologies: those of broad common interest (including Code T needs) and potential importance, and those of specific importance for future Space Exploration building block capabilities. In future, the development of those technologies that are uniquely needed for a specific science instrument or special mission system will be the responsibility of the implementing organization within NASA.⁹

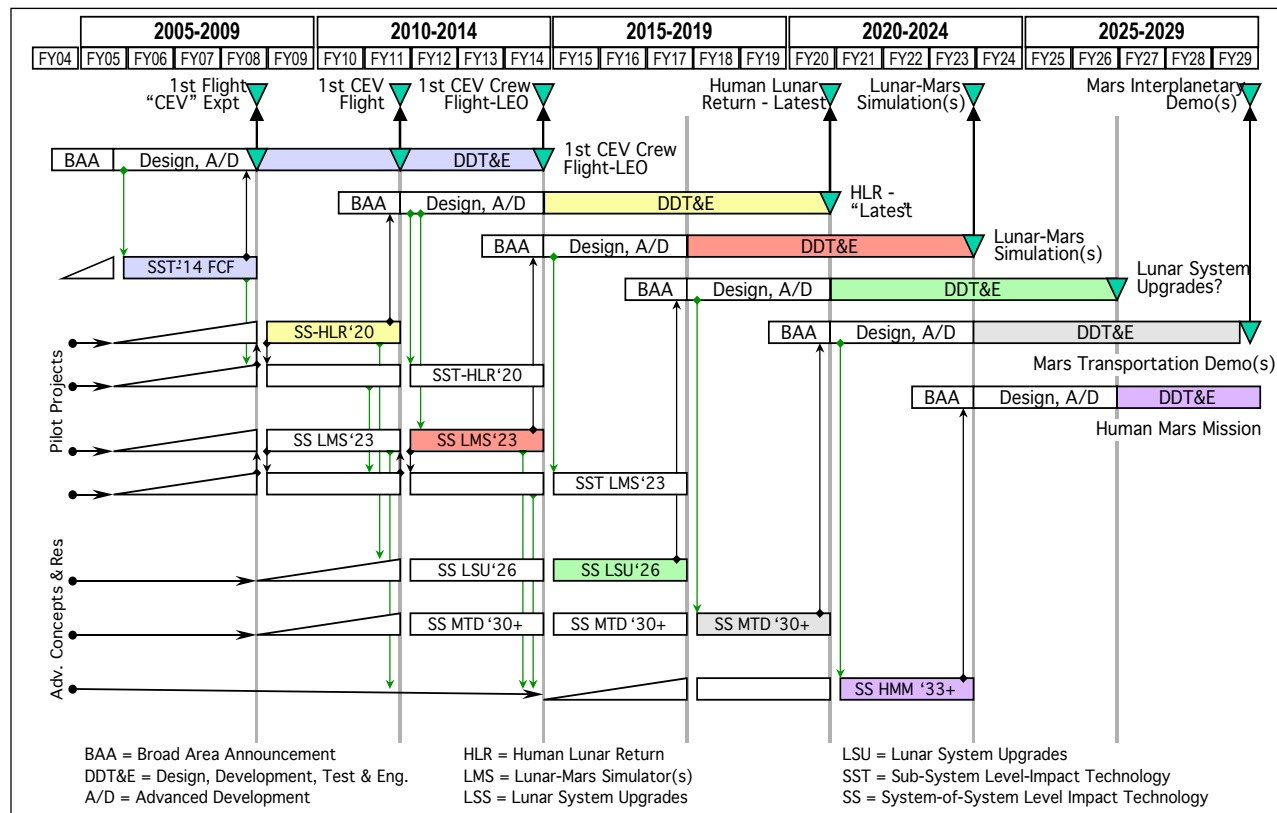


Figure 5-1 Integration of 'Cycles of Innovation' with Development Spirals

Making a clear determination of what goals and objectives will be addressed by the H&RT programs will be an important purpose of efforts during the implementation of this Formulation Plan. As indicated in APG 5HRT15 (see Appendix C), an integrated technology road map / plan will be completed during FY 2004; this plan will document appropriate interfaces regarding technology planning among NASA's several relevant Enterprises.¹⁰

⁹ As documented in the FY 2005 NASA Budget there are robust ongoing technology investments by the several NASA science Enterprises; through coordination among Code T and these organizations, no critical areas should be missed.

¹⁰ APG 5HRT15 calls for a road map addressing ASTP only; through this H&RT formulation process, this annual performance goal will be expanded to include all of ASTP, TMP and ITTP.

The Innovative Technology Transfer Partnerships (ITTP) program—including SBIR, STTR and the Technology Transfer Network programs—will continue to address the full range of NASA technology needs and interests (including, for example, Aeronautics-related subtopics within the SBIR program). Future ITTP projects will continue to be selected so as to support the broader scope of NASA technology needs. However, special emphasis will be placed on assuring that the needs of the Exploration Vision are well served by NASA's ITTP programs.

5.3 H&RT Projects and Other Technology Investments

H&RT efforts will also work to coordinate effectively with and—where possible—leverage other technology investments. Within OExS, this means that H&RT (ASTP, TMP and ITTP) will work closely with Project Prometheus and the Centennial Challenges program. (The latter collaboration is of particular importance.) External to OExS, this goal implies focused efforts to collaborate with other Enterprises concerning R&D (see Paragraph 5.2 above) and with other Agencies.

In order to support the latter objective, an Exploration Systems/Technology Coordination Group (ESTCG) has been formed. This coordination group, chaired by the OExS Development Programs Division Deputy Director for Human and Robotic Technology, will provide a vehicle to assure the greatest degree of coordination, information exchange, and cooperation among the several NASA Enterprises with responsibility for aspects of human and robotic exploration research and technology. The ESTCG will be comprised of the several NASA Headquarters organizations with an interest and/or a role in the development and validation of human and robotic technology. The following are the anticipated roles of the group:

- The CG will serve as a primary venue for communication on matters of general importance to the H&RT Theme and associated community of interest;
- The CG will provide interested parties with the opportunity to review and comment on pending NASA Research Announcements and other types of solicitations to assure good coordination among related technology programs;
- The CG will help to coordinate the annual development and implementation of the several H&RT programs of general interest, including SBIR, STTR, RASC, NIAC, and others (as appropriate);
- Also, the CG will serve as a common venue for review and discussion of progress in areas of research and technology of importance to the goals of the H&RT Theme; and,
- As needed, CG members will be invited to identify appropriate points-of-contact from among their respective program teams in all H&RT and related planning.

Section 6

H&RT Programs Formulation: Strategic Technical Guidance

6.1 Overview

The H&RT programs addressed by this Formulation Plan comprise three key programs: (1) the Advanced Space Technology Program (ASTP)¹¹; (2) the Technology Maturation Program (TMP),; and, (3) the Innovative Technology Transfer Partnerships (ITTP) Program.

The following section provides detailed guidance for formulation of H&RT programs (consistent with the scope specified in Section 1). Figure 6-1 provides the high-level work breakdown structure (WBS) for H&RT programs.¹²

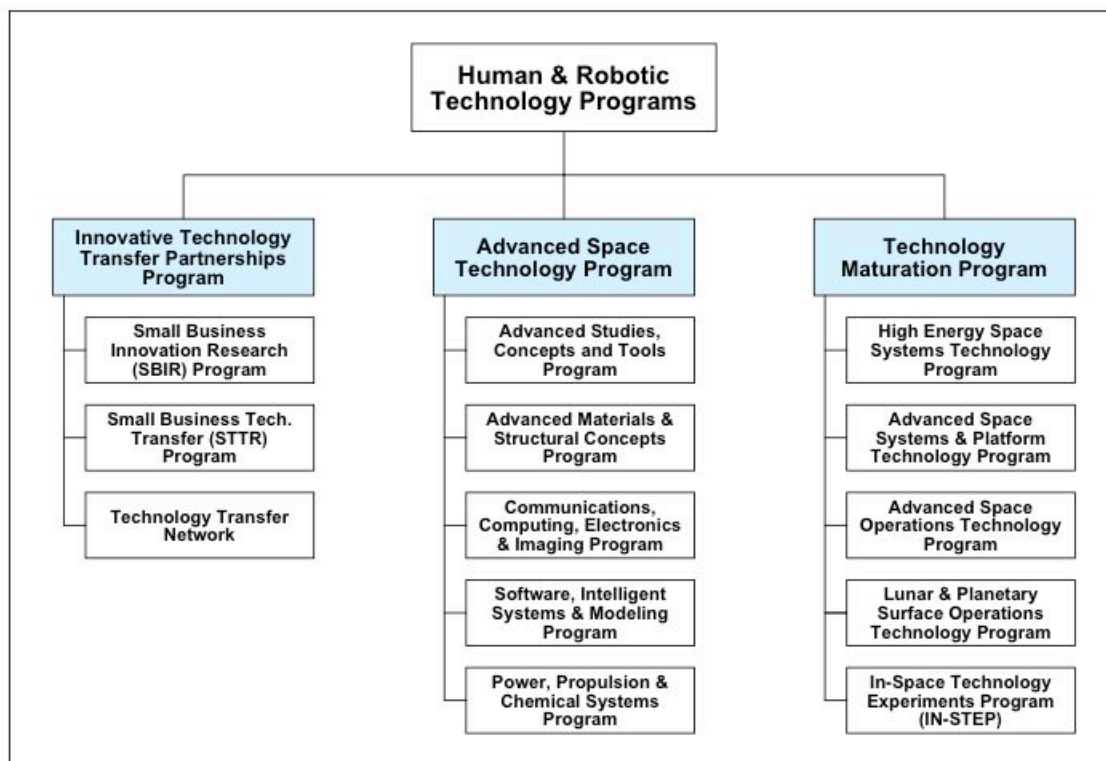


Figure 6-1 H&RT Programs Work Breakdown Structure

Each of the programs that comprise H&RT will undertake a highly focused initial process of program formulation and/or reformulation during the period through June-July 2004. This effort will follow a “strategy-to-task-technology” (STT) approach in establishing integrated plans for research and development to enable the Exploration

¹¹ Formerly the “Mission and Science Measurement Technology (MSMT) Program.

¹² Project Prometheus and Centennial Challenges Program not shown.

Vision, an integrated process for portfolio development and assessment, and initial program goals, objectives, budgets, schedules, metrics to measure progress, etc., for the several H&RT programs. The resulting family of coordinated programs and plans will support the appropriate application of Earned Value Management (EVM) techniques. See Section 8 for the schedule and major milestones associated with this Formulation Plan.

The process of H&RT program formulation is anticipated to be an ongoing effort; future adjustments will be made in light of new information obtained from ongoing R&D, data returned from future missions, and insights obtained from future studies. In addition, portfolios must be adjusted as the plans of other, contributing organizations change. Figure 6-2 illustrates an overview of this anticipated annual process for updating and refining H&RT program planning.

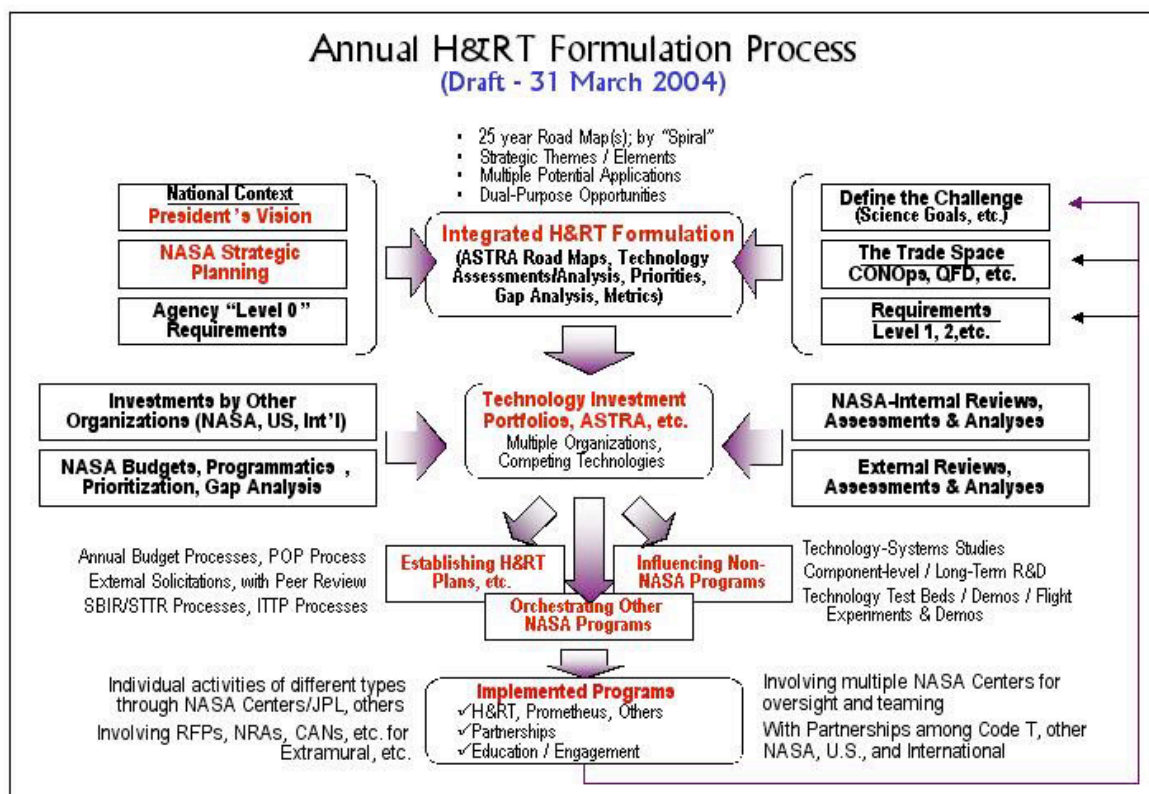


Figure 6-2 Annual H&RT Programs Planning Process (Preliminary)

6.2 Establishing Strategic Targets for H&RT Programs

The several programs that comprise the H&RT portfolio will be formulated to support a clear 'strategy-to-task-to-technology' (STT) approach. In other words, both the general principles and the specific contents of the H&RT investment portfolio will be derived from clear 'tasks' (i.e., quantifiable objectives concerning future human and robotic exploration systems, infrastructures or mission operations). And, in turn these 'tasks' shall be derived from clearly-defined 'strategic goals and/or goals/objectives'.

The following paragraphs outline the ‘strategic targets’ that have been established for the H&RT Programs. These include:

- (a) The ‘targeted level of impact’ that H&RT results are intended to achieve (see Paragraph 6.2.1);
- (b) The ‘strategic technical challenges’ that will be used to drive ‘systems-of-systems’ level planning for H&RT programs;
- (c) Detailed technical guidance as to the expected scope of each of the several H&RT element programs;
- (d) The focused linkages that will be established to ‘design reference architectures’ (and ‘design reference missions’) and the processes of ‘gap analysis’; and,
- (e) Assuring that H&RT investments in new technologies are of broad value to diverse future U.S. exploration and other space missions.

6.3 Portfolio Balance: Targeted Level of Impact

Human and Robotic Technology programs may address either ‘systems-of-systems level’ strategic technical challenges, or focused ‘subsystems level’ technology and/or capability gaps. In addition, H&RT programs may be targeted (as indicated in Section 5) on a variety of different timeframes, as well as toward both higher and lower risk—and payoff—objectives.

Figure 6-3 summarizes graphically the planned ‘mixed portfolio’ that will be pursued during H&RT program formulation during FY 2004, providing in the figure the overall H&RT strategy with regard to ‘impact’ and ‘timeframe.’ In this diagram, recall from Figure 5-1 that technology products with a targeted ‘timeframe of impact’ of +3 years correspond to subsystem-level capability gaps in the “Spiral 1” Project Constellation systems (including the Crew Exploration Vehicle (CEV), which will enable the first crew flight by 2014. Similarly, technology products with a targeted ‘timeframe of impact’ of +6 years correspond to systems-of-systems impact technologies for “Spiral 2” of Project Constellation systems which will enable an initial human lunar return (HLR) by no later than 2020. (And so on for the remaining timeframes in Figure 6-3.)

Figure 6-4 provides an alternate view, integrating the two policies to allow comparison of the notional level of investment in each category.

Because H&RT represents the major of NASA’s investment in both near- and far-term technology for future space exploration, present, the strategy for H&RT programs is to pursue a ‘mixed portfolio’ approach in which investments with varying levels of potential impact and addressing various timeframes will be pursued.

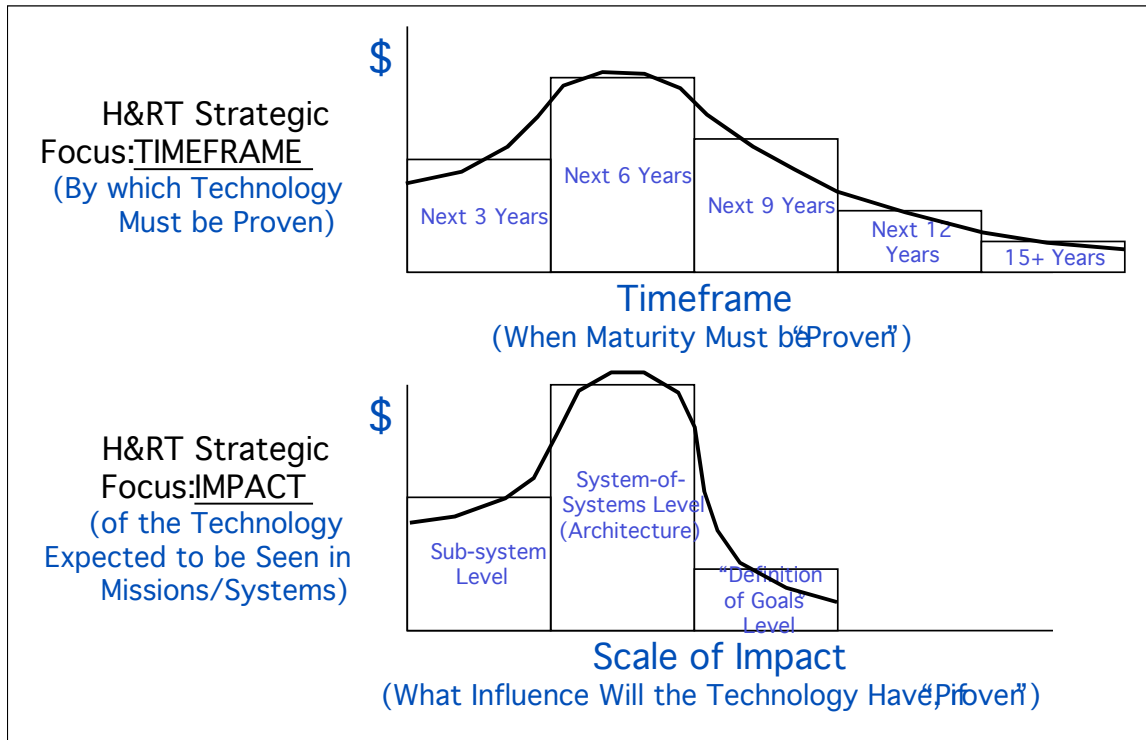


Figure 6-3 Overall View of Planned Portfolio Balance for H&RT Programs

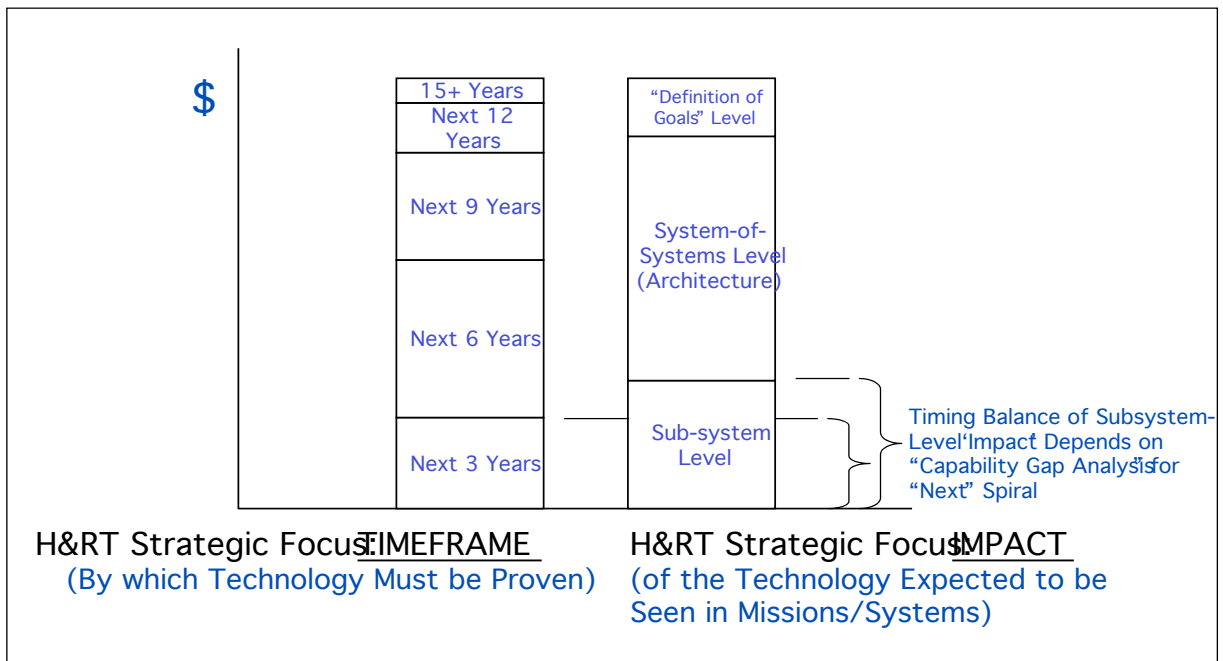


Figure 6-4 Integrated Comparison of Policy Targets for Timeframe and Impact

The detailed correlation of these timeframes with the forecast of future events and activities in support of the National Vision for Space Exploration may be found in Appendix J.

6.4 Strategic Technical Challenges

6.4.1 The Concept of Sustainability

A central concept of the new U.S. National Vision for Space Exploration (see Appendix C) is that space exploration activities must be ‘**Sustainable**’. In the future, it will be unacceptable to achieve a major exploration goal (i.e., as was true during the 1960s Apollo Program), only to experience a decades-long cessation of major exploration accomplishments or an integrated program of exploration.

Successful realization of a **sustainable**, long-term and well-orchestrated campaign of space exploration involves addressing three primary technical challenges: affordability, reliability/safety, and effectiveness; figure 6-4 summarizes the conceptual relationship among these characteristics.

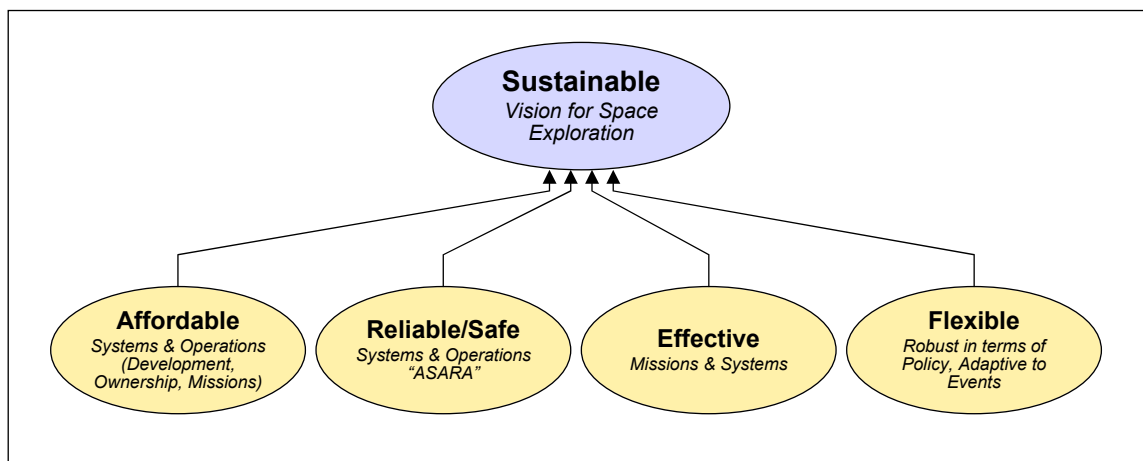


Figure 6-4 Relationship Among “Sustainability” and Other Key Measures

In particular, concerning...

- **Affordability.** To be *sustainable*, future space exploration systems and infrastructures, and the missions pursued using them must be affordable. In other words, the costs for design, development, test and engineering (DDT&E) for new space exploration systems must be consistent with projected future year NASA budgets. (The same is true for the recurring costs of additional copies of all exploration systems.) Similarly, the costs associated with operating these systems in future space exploration missions must be consistent with projected future year NASA budgets.

- **Reliability/Safety.** To be *sustainable*, future space exploration systems and infrastructures, and missions pursued using them must be reliable, and when astronauts are involved, they must be *as safe as reasonably achievable* (ASARA).¹³ In other words, the reliability of the system or infrastructure being operated in a mission must satisfy some well-established and accepted reliability objective. (For example, the objective may be stated as: “the probability of mission success shall not be less than 99 chances out of 100.”) In the case of human space flight, the safety of the system being used or the mission being pursued must also satisfy some well-established and accepted safety objective. (For example, the objective may be stated as: “the probability of loss of crew during the mission shall not be greater than 1 chance in 1000.”)
- **Effectiveness.** To be *sustainable*, future space exploration systems and missions must be effective. In other words, the capabilities of a new system or infrastructure must be worth the *costs* of developing, building and owning them. The goals and objectives achieved by missions using those systems and infrastructures must be worth the *costs* and *risks* involved in operating them. Effectiveness must be determined case-by-case, based on the specific design objectives of a new system or infrastructure, and based on the detailed mission objectives (e.g., science objectives) that may be achieved.
- **Flexibility.** To be *sustainable*, future space exploration systems, missions and programs must be flexible. In other words, the families of new systems, infrastructures and even technologies should be capable of adapting to changing policy objectives and to future events—including both research and development results and scientific discoveries. Also, our systems and infrastructures developed for a given set of missions should be extensible to later missions.

6.4.2 H&RT Strategic Technical Challenges

Based on the three aspects of ‘sustainability’ suggested above, a series of ‘strategic technical challenges’ (STCs) may be defined which represent ‘systems-of-systems’ level issues.¹⁴ Although it is certainly possible to execute a human lunar return (HLR) using existing technologies and concepts derived from the 1960s (i.e., using an Apollo-like architectural approach), such an architecture is unlikely to lead to a ‘sustainable’ program. Instead, a number of promising new approaches for sustainable human and robotic exploration must be identified and the ‘systems-of-systems’ level innovations necessary to realize those approaches must be pursued. As indicated in

¹³ The concept of “ASARA” is analogous to the goal in nuclear systems or wherever radiation is involved that the risk involved in operations must be “as low as reasonably achievable” (ALARA). ALARA does not mean that risks are “zero”, since everything in life involves some risk, but rather it implies that—given the goals and objectives of a given activity—the risks that remain after all reasonable engineering and design efforts have been undertaken should be ‘as low as reasonably achievable.’

¹⁴ Past studies such as the NASA Exploration Team (NEXT) and the results of the Decade Planning Team (DPT) provided key inputs to define these STCs.

Figure 5.1, the resolution of these STCs must be completed prior to final decisions on the architecture of future exploration missions—if incorporation of these capabilities is to be a serious option for those missions.

The systems challenges (for both in space and on surface space systems and operations) that must be surmounted in order to realize these new approaches include:

- Margins and redundancy in diverse subsystems, systems and systems-of-systems—but particularly those that must execute mission critical operations (such as transportation or life support) with the prospect of significant improvements in robustness in operations, reliability and safety. Margins and redundancy can also increase flexibility in future applications.
- Reusability — using vehicles and systems during multiple phases of a single mission, and/or over multiple missions instead of ‘throwing away’ crew transportation, service modules, propulsion stages, and/or excursion systems after only a single mission.
- Modularity — employing common, redundant components, subsystems and/or systems that can improve reliability and support multiple vehicles, applications and/or destinations—with the potential for significant reductions in cost per kilogram. Some approaches to modularity may also improve long term flexibility by allowing graceful evolution of capabilities.
- Autonomy — making vehicles and other systems more intelligent to enable less ground support and infrastructure, including the goal of accelerating application of ‘COTS’ and COTS-like computing and electronics in space.
- “ASARA” Human Presence in Deep Space – making it possible for humans to operate affordably and effectively in deep space and on lunar/planetary/other surfaces for sustainable periods of operations—while assuring that they are ‘as safe as reasonably achievable’.
- In-Space Assembly – docking vehicles and systems together on orbit instead of launching pre-integrated exploration missions from Earth using very heavy launch vehicles, and including in space maintenance, servicing, reconfiguration, evolution, etc., for exceptionally long-duration deep space operations.
- Reconfigurability – deploying systems that can be reconfigured following initial deployment, to enable adaptation to new circumstances, evolution at the systems-of-systems level as new elements are added, or to support high level system options. Both in-space assembly and reconfigurability can enable increased levels of flexibility future systems and infrastructures.
- Robotic Networks – enabling ‘networks’ of cooperating robotic systems to be deployed that can work cooperatively to prepare landing sites, habitation, and/or resources and to extend the reach of human explorers.
- Affordable Logistics Pre-positioning – sending spares, equipment, propellants and/or other consumables ahead of planned exploration missions to enable more flexible and efficient mission architectures.

- Energy-Rich Systems and Missions – including both cost-effective generation of substantial power, as well as the storage, management and transfer of energy and fuels to enable the wide range of other systems-of-systems level challenges identified here).
- Space Resource Utilization – manufacturing propellants, other consumables and/or spare parts at the destination, rather than transporting all of these from Earth.
- Data-rich virtual presence – locally & remotely, for both real-time & asynchronous virtual presence to enable effective science and robust operations (including tele-presence and tele-supervision; tele-science; etc.). Data-rich operations can be inherently more flexible in responding to changing goals and circumstances than those that are not.
- Access to Surface Targets that is precise, reliable, repeatable and global for small bodies, the Moon, Mars and other destinations—including both access from orbit and access from other locations on a planetary surface through the use of advanced mobility systems.

As a minimum, the planning within the several programs of the H&RT (ASTP, TMP and ITTP) should establish viable plans to address each of these strategic technical challenges. The overarching objective is for the H&RT investment portfolio to make possible a range of new ‘systems-of-systems’ options that will enable future ambitious missions to be reliable/safe, affordable and effective in realizing the goals and objectives of the U.S. Vision for Space Exploration.

The following Section provides initial definitions of the principle technical themes that must be pursued within each of the several H&RT element programs in order to advance the STCs stated above—or our understanding of why these STCs cannot yet be overcome.

Section 7

H&RT Programs Formulation: Detailed Technical Guidance

7.1 Overview

The following section provides detailed technical guidance for the several Element Programs within the H&RT investment portfolio, based on the strategic-to-task-to-technology approaches described in Section 6 above.

H&RT Goals and Objectives

The investments made through the Human and Robotic Technology (H&RT) programs will provide the critical foundation of knowledge and validated technologies for achieving the Vision for Space Exploration, while delivering technologies of broad common value to NASA, the Nation and the U.S. economy.

Accomplishing this goal will entail the following principal objectives (in approximately order of priority).

- Establish the viability (or non-viability) of various major systems and systems-of-systems options for longer-term future exploration systems, with a focus in the next 6-9 years on the systems-of-systems level issues that will determine how we return to the Moon by no later than 2020.
- Address on a priority basis any critical gaps in needed capabilities and/or technologies that emerge during definition of the systems that OExS will 'build next'—for example, in the near term, H&RT will address capability gaps that may exist for "Spiral 1" (leading to the 2014 first flight of the CEV with crew).
- Develop, demonstrate and deliver component-, subsystem-, or system-level technologies for consideration by system developers that may provide an alternative chosen technologies and provide a substantial improvement in key aspects of systems-level characteristics. This will be a lower priority within H&RT, to be addressed as appropriate and possible given competing demands for funds.
- Develop, demonstrate and transfer technologies of broad common value, for NASA missions, other government applications and for the benefit of the economy.
- Assure the timely creation and effective management of innovative research and technology development and transfer partnerships to accomplish better NASA's exploration, science and technology goals.

The following sections provide the detailed goals and objectives of the major programs and element programs of the H&RT investment portfolio.

7.2 Advanced Space Technology Program

7.2.1 ASTP Summary

The ASTP is the portion of the H&RT portfolio that addresses relatively low TRL technologies, with the goal of exploring innovative concepts and advancing a range of high-leverage technologies. The goal is to validate these new concepts and technologies experimentally or analytically and to transition them for application in the Exploration Systems Enterprise and other NASA Enterprises. The nominal path for this transition will be through the Technology Maturation Program (discussed below), which will adopt, mature and demonstrate the most promising candidates for ultimate transition to flight system development projects.

7.2.2 ASTP Element Programs

The ASTP integrates and realigns current projects from the FY04 Code R Mission and Science Measurement Technologies (MSM) theme with the emerging priorities of the Office of Exploration Systems. FY'05 will be a transition year in which various programs are integrated as parts of Human and Robotic Technology, and former MSM projects or sub-projects are assigned to one of five AST Element Programs. These programs are:

- Advanced Studies, Concepts And Tools Program
- Advanced Materials and Structural Concepts Program
- Communications, Computing, Electronics & Imaging Program
- Software, Intelligent Systems & Modeling Program
- Power, Propulsion & Chemical Systems Program

Figure 6-2 summarizes how the former MSM projects will be mapped into the new AST Program Elements.¹⁵ Work conducted within the AST Program shall be aligned with the Exploration Vision (February 2004) and all OExS POP guidelines (March 2004). All planning, including POP inputs shall be so aligned. Specific traceability to the Exploration Vision shall be incorporated into POP responses to clearly indicate the alignment of the same to this Vision.

¹⁵ See the March 2004 OexS POP Guidelines for additional information on this mapping.

7.2.3 ASTP Planning Leadership¹⁶

Program formulation for the several ASTP Element Programs will be led by a single program manager at NASA Headquarters, with the support of a NASA Center-based planning team, drawn from the Field Centers with competency/expertise appropriate to the technical areas involved. Element Programs will be subdivided into competitively selected Projects, Sub-Projects and Tasks. The planning team will provide Program Element plans including milestones, budgets, work force and facility requirements by June 1, 2004 to the ASTP Program Director, who will incorporate these inputs into integrated H&RT planning (consistent with this formulation plan). Details concerning ASTP program formulation and planning leadership information are provided in Appendix I.

ASTP Approval Authority. The overall ASTP plan will be subject to the review and concurrence of the Deputy Director for H&RT, Development Programs Division (OExS) and the review and approval of the Director, Development Programs Division. The several Element Program plans will be subject to the review and concurrence of the Program Director, Advanced Space Technology Program, and the review and approval of the Deputy Director for H&RT, Development Programs Division (OExS).

7.2.4 Advanced Studies, Concepts And Tools Program

This program will explore revolutionary exploration system concepts and architectures; performs technology assessments to identify and prioritize mission enabling technologies; develops advanced engineering tools for systems analysis and reducing mission risk; and conducts exploratory research and development of emerging technologies with high potential payoff. Activities within this ASTP Element Program will provide products in support of both ASTP and TMP within H&RT, as well as for external customers/stakeholders—particularly within the OexS Requirements Division.

This Element includes the following former MSM projects: Advanced Systems Concepts; Space NASA Research Announcements (NRAs); System Reasoning for Risk Management; Resilient Systems and Operations; Knowledge Engineering for Safety and Success; and the Nanotechnology URETI (at UCLA). Note that this program includes both the NASA Institute for Advanced Concepts (NIAC) and the Revolutionary Aerospace Systems Concepts (RASC) program. The Advanced Studies, Concepts and Tools Element Program also includes a Competitive Opportunities line for the competitive selection of future work in this area (to developed in accordance with the H&RT Program Formulation Plan (see above)).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ that will take responsibility for delivery of the appropriate products.

¹⁶ Note: the Program Formulation leadership approach outlined here is an update from the original concept provided in the OExS POP Guidelines (See Appendix D). The plan presented here supercedes the earlier approach.

Technical Themes. This program will be responsible for advanced studies, concepts and related activities to inform future decisions concerning all H&RT programs (including ASTP, TMP and ITTP). In addition, the program will develop prototypes of new models and tools for use by exploration requirements studies and activities (for example, by the Requirements Division of the Office of Exploration Systems). Major ASCT technical themes will include the following:

- **Advanced Concepts.** This theme includes intramural¹⁷ and extramural¹⁸ advanced systems concepts study efforts; low TRL (e.g., TRL 2-3) exploratory research and development of emerging technologies with high potential payoff through experimental and/or analytical validation; etc.
- **Technology-Systems Analysis.** This theme includes technology assessments and forecasts; integrated analyses of potential system and/or architecture impact of new technologies, etc. This theme also encompasses support for technology road map definition.
- **Technology Databases.** This theme includes various types of technology databases, for both internal use in analyses and planning, as well as for external communications.
- **System and Infrastructure Analysis Tools.** This theme addresses the simulation modeling environment, databases, system models, discipline-oriented analysis tools, parametric-based risk analysis and tools, probabilistic risk analysis (PRA), etc.
- **Technology-Systems Verification and Validation.** This theme includes the development of technology testing, verification and validation requirements based on architectures, concepts of operations, PRA assessments, etc.
- **Interfaces and Interface Standards.** This theme includes identification of existing standards, assessment of the role of standards in, and impact of standards on technology choices, establishing interfaces standards for novel systems concepts (including intelligent modular systems)

These themes should be used to guide the formulation of the Advanced Studies, Concepts and Tools (ASCT) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

¹⁷ For example, intramural activities such as the former Revolutionary Aerospace Systems Concepts (RASC) program.

¹⁸ Including the NASA Institute for Advanced Concepts (NIAC).

7.2.5 Advanced Materials and Structural Concepts Program

This program will develop high-performance materials for vehicle structures, propulsion systems, and spacesuits; structural concepts for modular assembly of space infrastructure and large apertures; lightweight deployable and inflatable structures for large space systems and crew habitats; and highly integrated structural systems and advanced thermal management technologies for reducing launch mass and volume.

This Element includes the following MSM projects: Revolutionary Spacecraft Systems; Large Space Systems; Modular and Distributed Systems; Extreme Environment Systems (Spacesuit materials; Space Environments & Effects); Nanotechnology materials URETI (at Princeton); Space NRAs (Large Aperture Technology). The Advanced Materials and Structural Concepts Research Element also includes a Competitive Opportunities line for the competitive selection of future work in this area (to developed in accordance with the H&RT Program Formulation Plan (see above)).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the 'program formulation team' will take responsibility for delivery of the appropriate products.

Technical Themes. This program will be responsible for low-TRL development and testing of novel materials and structural concepts for a wide range of future exploration applications. Major AMSC technical themes include the following:

- **Advanced Materials.** This theme includes high performance structural and thermal materials, space-durable materials, radiation protection materials, nano-structured materials, and computational design of materials properties.
- **Structural Concepts, Dynamics and Controls.** This theme address research and development of concepts for rigid, deployable, inflatable and erectable structures. It also involves the application of advanced controls-structures interaction (CSI) techniques for measuring and controlling structural dynamics and geometry.
- **Mechanisms and Interconnects.** This theme will involve research related to novel rotating devices, motors and actuators, and tribology and seals. It will also develop intelligent structural, electrical, and fluid interfaces to enable the assembly (or 'self-assembly') of modular systems.
- **Flexible Fiber Systems.** This theme will involve flexible material systems incorporating fibers, fabrics, films, and coatings for diverse exploration system applications, including extravehicular activity (EVA) systems, surface robotics, membrane structures, and other areas.
- **'Smart' Materials and Structures.** This theme will address smart materials; highly integrated material systems that incorporate embedded electronics, sensors, and actuators; and multifunctional and adaptive structures that can be reconfigured in response to changing mission conditions.
- **Space Environments and Effects.** This theme will address methods for predicting and mitigating the effects of space environments (e.g., vacuum, extreme temperatures, atomic oxygen, ultraviolet radiation, charged and neutral

particle radiation, meteoroids and orbital debris, dust and contaminants) on materials, electronics, and other spacecraft systems.

These themes should be used to guide the formulation of the Advanced Materials & Structural Concepts (AMSC) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect future specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.2.6 Communications, Computing, Electronics & Imaging Program

This program will develop advanced space communications and networking technology; high-performance computers and computing architectures for space systems and data analysis; low-power electronics to enable robotic operations in extreme environments; and imaging sensors for machine vision systems and the characterization of planetary resources.

This Element includes the following MSM projects: Information Technology Strategic Research (Interdisciplinary; Bionanotechnology); Space Communications; Computing, Network & Information Systems; Advanced Measurement and Detection; Science Measurement Systems; Extreme Environment Systems (Systems Survival Technology); nanotechnology sensing and electronics URETI (at Texas A&M); Modular and Distributed Systems (Distributed Spacecraft Technology); Space NRA’s (Advanced Measurement and Detection Technology; Low Power Microelectronics Technology). The Communications, Computing, Electronics, and Imaging Research Element includes a Competitive Opportunities line for the competitive selection of future work in this area (to developed in accordance with the H&RT Program Formulation Plan (see above)).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ that will take responsibility for delivery of the appropriate products.

Technical Themes. This program will be responsible for low-TRL development and testing of novel communications, computing, electronics and imaging concepts and technologies for diverse future exploration applications. The special focus is on new devices and components for use in future space systems. Major CCEI technical themes include the following:

- **Space Communications and Networking.** This theme will pursue advanced physical link layer components such as transmitters and receivers, as well as data link, network and protocol layer technologies for navigation and communication networks. Technologies will be developed to support interplanetary links, in-space and surface operations, and intra-vehicle networks.
- **In-Space Computing and Avionics.** This theme will develop architectures and components required for space-based computing and avionics systems.

Architecture efforts will emphasize modular, fault-tolerant approaches that leverage commercial standards and COTS devices. Component work will focus on capabilities for enhance general- and special-purpose processing, with particular interest in fault-tolerant, reconfigurable processors, micro-controllers, and storage devices

- **Ground-Based High-End Computing.** This theme will develop innovative high-end computing architectures for ground-based processing that substantially increase computational effectiveness for critical exploration applications. The effort will include both conventional electronics-based approaches as well as long-term efforts based on revolutionary technologies. This theme also includes modeling and performance assessment of novel computing architectures.
- **Extreme Environment Electronics.** This theme will develop radiation-tolerant, wide-temperature-range digital, analog, mixed signal, dynamic member and RF electronic components, and integrated modules suitable for operation in the extreme environments of the Moon, Mars and other deep space destinations. Efforts will emphasize supporting electronics for sensors, actuators and communications.
- **Sensing and Imaging.** Priority areas for this theme fall within 3 broad categories: Orbital remote sensing for topographical and resources mapping and atmospheric profiling; Control-loop sensing for robotic functions such as rendezvous and docking, assembly and construction, and precision landing; In situ sensing, including surface and subsurface detection of priority resources, radiation measurements, and characterization of mechanical, thermal, electromagnetic and radiation shielding properties of local materials.

These themes will be used to guide the formulation of the Communications, Computing, Electronics & Imaging (CCEI) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.2.7 Software, Intelligent Systems & Modeling Program

This program will develop reliable software and revolutionary computing algorithms; intelligent systems to enable human-robotic collaboration; intelligent and autonomous systems for robotic exploration and to support human exploration; and advanced modeling and simulation methods for engineering design and data analysis.

This Element includes the following MSM projects: Intelligent Systems; Collaborative Decision Systems; Information Technology Strategic Research (Evolvable Systems; Automated Software Engineering Technology; Intelligent Controls and Diagnostics; Neuroelectric Machine Control; Revolutionary Computing Algorithms); Reliable Software. The Software, Intelligent Systems, and Modeling Research Element also includes a Competitive Opportunities line for the competitive selection of future

work in this area (to developed in accordance with the H&RT Program Formulation Plan).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the 'program formulation team' will take responsibility for delivery of the appropriate products.

Technical Themes. This program will be responsible for low-TRL development and testing of novel software, intelligent systems and modeling concepts and technologies for diverse future exploration applications. This element program will also be the focal point for H&RT utilization of NASA or other national supercomputing assets. Major SISIM technical themes include the following:

- **Autonomy and Intelligence**

Autonomy is a combination of three attributes: task complexity, robustness to unexpected circumstances, and level of human commanding. Any program or device that can perform complex tasks in changing or incompletely known environments with little human oversight is by this definition autonomous. Thus from a systems engineering point of view, autonomy should be considered for any task that is non-trivial, is performed in an environment that cannot be fully predicted or controlled, and for which human oversight is limited or unavailable. This last criterion, the unavailability of human oversight, plus the finite speed of light, are the fundamental source of NASA-unique autonomy requirements – no other agency, and generally no private companies who are not working for NASA, need to perform complex tasks far enough from earth that detailed human oversight becomes impractical. Applications of autonomy to exploration fall into three broad classes:

- 1) Precursor missions – This class includes rovers, orbiters, climbers, drills, assembly robots, and other autonomous craft used to scout and construct habitats in advance of human exploration. The fact that such devices must operate far from any physical human assistance imposes unique robustness requirements.
- 2) Intelligent devices and systems (life support, ISRU, power, propulsion, etc.) – This is a broad class that includes any device or system that needs to be able to perform complex tasks robustly with limited human oversight. These applications are sometimes called “imobots” since they have many of the same autonomy requirements as robots but do not actually move.
- 3) Robotic assistants – This class includes free fliers, rovers, drills, climbers, assembly robots and other robotic devices that work as astronaut assistants. These applications have unique requirements imposed by the need to work cooperatively with humans at human time scales (e.g., traverse speeds must be much higher than the MER rovers).

- **Crew-Autonomy Interface Technologies**

Crew-Autonomy Interface Technologies (CAIT) include the auditory, visual, and haptic media that provide the direct communication between crewmembers and autonomous systems, as well as the semantic and causal relations among display elements, task components, and system functions. These two aspects, the medium

and the content, are inextricably linked in the interface design and implementation process. Components of CAIT fall into two broad categories:

- 1) Multimedia systems for augmented and virtual reality, virtual presence, and telerobotic control may include user interfaces integrated with EVA suits, including haptic, speech, and non-speech audio components. Such technologies would be most useful in real-time EVA activities such as in-space construction and human-robotic surface activities. These systems place heavy demands on the design of both the medium and the content.
- 2) Embedded training, aiding, and advisory systems have many applications, such as IVA, habitat, and ground operations. Carefully designed interfaces will also be needed to allow crewmembers to maintain situation awareness in largely autonomous process control and vehicle operations, including goal-level commanding of remote autonomous vehicles and robots. For the most part, these systems stress the content - if the content is correct, the design of the medium is usually not a major challenge; on the other hand no media-based design can compensate for incorrect content.

- **Multi-Agent Teaming**

As mission durations grow and as tasks in space become more complex, teams of humans and automation (robots or software systems) will be necessary to accomplish mission goals. Teams may involve robots and humans working in close proximity (i.e., shoulder to shoulder), humans and robots working together but distributed across space and/or time, humans working together but distributed across space and/or time and humans and automation agents working together to solve problems and improve operations. These teams will need to be supported by a software infrastructure that configures, manages, coordinates and informs these teams. The goal of this teaming infrastructure is to optimize the deployment of critical resources, reduce the exposure of humans to unsafe conditions and reduce the size (and cost) of ground control operations. These teams must be flexible and adaptive and the teaming infrastructure needs to ensure that the right information gets to the right team member at the right time. Implementing such multi-agent teams will require a software infrastructure with the following components:

- 1) Command and control architecture for adjustably autonomous human-robot teams.
- 2) Software agents for coordination of human-robot teams in-space and human-human teams on the ground.
- 3) Planning and scheduling for human-robot teams in-space and human-human teams on the ground.

- **Software Engineering for Reliability**

NASA missions in general show a clear trend towards an increasing percentage of mission functionality being implemented in software. Systems engineers have aggressively utilized increased computing power (flight and ground) to achieve impressive gains in mission capabilities, resulting however in a significant increase in the sizing and complexity of mission software. Not surprisingly, these trends have led to a brittleness, lack of reusability, and lack of dependability that leads to software being identified legitimately as a separate and significant mission risk factor. Accordingly, the need for greater rigor coupled with

knowledge and use of modern software engineering tools and techniques have come to the forefront. Moreover, the most effective way (often the only way) to update mission capabilities as required once operations have commenced is via software changes. As human-robotic space systems must be highly dependable, in the strictest safety- and mission-critical sense, software modifications to them need to be carried out in an effective, rapid, and most dependable manner.

Future NASA mission trends and needs taken together with advanced in software engineering point the way to the following objectives:

- 1) increased software reliability, including the ability to develop software components that are provably robust and can be trusted in any integration context,
- 2) increased software development predictability, encompassing the trades among functionality, cost, schedule and risk,
- 3) increased software reusability (both design artifacts such as behavior models, and code), including the advantages of identifying, pre-integrating and pre-validating core functionality,
- 4) methodologies and tools for providing for software assuredness, and
- 5) the imperative to extend traditional verification and validation techniques to human-robotic systems, including autonomous systems.

- **Health Management Technologies**

Health Management (HM) technologies determine health of components/systems and subsystems for the purpose of informed-decision making either with humans in the loop or via autonomous control. HM is applicable to virtually all aspects of space exploration – launch vehicles, CEV, upper stages, insertion/ascent stages, planetary habitats, etc. Several technologies contribute to an integrated health management capability for a system/subsystem. These include:

- 1) Fault Detection and Diagnosis (including discrimination between component failures, sensor failures, actuator failures and nominal transients)
- 2) Prognostics – the estimation of remaining life
- 3) Information Fusion
- 4) Degradation Management
- 5) Smart Data Compression
- 6) HM Technology Design Tools – HM needs to be incorporated as an integral part of the design process rather than an add-on. This will require a paradigm shift.

- **Modeling, Simulation, and Visualization**

Modeling and Simulation (using software) describe algorithmic techniques for mathematically representing real-world objects or environments for the purpose of analysis, prediction, and control. Visualization, in this context, involves presenting modeling and simulation results in an understandable visual form to a human. Modeling, Simulation, and Visualization techniques are used for systems analyses, engineering design, and engineering and scientific data analysis. The techniques are used during various phases of the engineering systems life cycle, from conception trade studies through operations. Specific research areas needed include:

- 1) Model-based autonomy,
- 2) Failure modeling,

- 3) Human-System Behavior Modeling,
- 4) Testing data reflected back into model updates,
- 5) Modeling Frameworks, and
- 6) High-end Computing Applications.

These themes should be used to guide the formulation of the Software, Intelligent Systems & Modeling (SISM) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

These technical themes will be formulated in close collaboration with several Technology Maturation Program elements (e.g., in the area of robotics for both Advanced Space Operations as well Lunar & Planetary Surface Operations). In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.2.8 Power, Propulsion & Chemical Systems Program

The Power, Propulsion, and Chemical Systems Research and Technology Program develops high-efficiency power generation, energy storage, and power management and distribution systems to provide abundant power for space and surface operations; advanced chemical, and electrical space propulsion systems for exploration missions; chemical systems for the storage and handling of cryogenics and other propellants; chemical systems for identifying, processing, and utilizing planetary resources; and chemical detectors and sensors.

This Element includes the following MSM projects: Energetics. The Power, Propulsion, and Chemical Systems Research Element also includes a Competitive Opportunities line for the competitive selection of future work in this area (to be developed in accordance with the H&RT Program Formulation Plan (see above)).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ will take responsibility for delivery of the appropriate products.

Technical Themes. The Power, Propulsion and Chemical Systems (PPCS) Program will pursue low-TRL technology research and development across a wide range of topics related to advanced power, propulsion and various chemical systems topics. Major PPCS technical themes include the following:

- **Energy Conversion.** This theme will address photovoltaic conversion, thermophotovoltaic conversion, thermoelectric conversion and thermodynamic conversion (heat engines), etc.
- **Power Management and Distribution.** This theme will include research and technology development in topics related to advanced power cabling (including high voltage, superconductors, nano-tube applications, etc.), power management (e.g., modular and/or intelligent power switching),

- **Energy Storage.** This theme will include batteries, flywheels, fuel cells, etc.; for applications in both primary energy storage and regenerative energy storage systems. Also includes storage of reactants (e.g., for fuel cells), but in collaboration with other element programs. Note: electrochemical energy conversion is addressed here, rather than in ‘energy conversion’ above.
- **Thermal Management.** This theme will involve technologies for waste heat management, movement and rejection; technologies including light-weight and/or high-temperature radiators, heat pipes, heat sinks, etc. Also includes cryo-coolers and related low-temperature systems.
- **Thermal-, Electrical Chemical, and Biological-based Processing of Materials.** This technology theme will include materials processing and conversion by thermal, electrical, and chemical systems, and by biological organisms such as genetically-engineered microbes (e.g., in support of applications for *in situ* resource utilization, life support systems, etc.).
- **Advanced Chemical Propulsion.** This theme will address advanced cryogenics, storables, hybrids, monopropellants, recombinant energy and metallic hydrogen; micro- and meso-rocket concepts; advanced engine concepts and cycles; and engines that can use chemical propellants produced from in-situ resources.
- **Advanced Electric/Electromagnetic Propulsion.** Technology development related to this theme will include both electric and electromagnetic propulsion (e.g., ion thrusters, hall thrusters, plasma-based thrusters, magneto-hydrodynamic (MHD) thrust augmentation, magneto-plasmadynamic (MPD) thrusters, etc.), micro-thrusters, and electric propulsion systems that can use propellants produced from in-situ resources.
- **Novel Propulsion Concepts.** This theme will involve novel propulsion concepts of various types, including electromagnetic and pneumatic launch assist; advanced tethers; photon-sails and magnetic-sails; and advanced fusion or antimatter based propulsion systems (beyond Prometheus, which addresses fission based power and/or propulsion).
- **Novel Power and Transmission Technologies.** This theme will involve a range of novel power technologies, including micro- chemical and thermal systems (M-CATS), beamed energy (e.g., solar-pumped lasers, RF wireless power transmission), bio-chemical based energy systems, and others.

These themes should be used to guide the formulation of the Power, Propulsion, and Chemical Systems (PPCS) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.2.9 ASTP Resources Planning

Details concerning resources planning are provided in the OExS POP Guidelines. Unallocated funding in FY05 and out years has been used to establish a new funding line called “Competitive Opportunities” within each Program Element. This funding will be used for the competitive selection of future work so that the technical content of each Element is realigned with H&RT objectives.

In both POP responses and the Element Program Plans, Civil Service Full-Time Equivalents (FTEs) and on-site contractor Work-Year Equivalents (WYEs) will be identified. Overall, all budget discussions will be conducted in full cost. All full cost budgets at the sub-project level and above will be discussed in terms of direct (procurement, direct civil service workforce, salaries, benefits, travel, service pools); and G&A. Management staffing is estimated as roughly 5% of the overall budget and is allocated proportionally to each Project.

Funding for SBIR/STTR proposal evaluators and Contracting Officer’s Technical Representatives (COTRs) will not be included in the SBIR/STTR Program Management Budget. Where appropriate, resources to cover these costs should be included in the associated AST Program Element.

7.3 Technology Maturation Program

7.3.1 TMP Summary

The H&RT Technology Maturation Program (TMP), comprising mid- to high-TRL technology maturation, demonstration and flight experiments, will pursue new technologies in the areas of high energy space systems, advanced space systems and platforms, advanced space operations, and lunar & planetary surface operations. The program will advance key technologies required to enable the U.S. Exploration Vision, with a focus on the human and robotic exploration of the Moon, Mars and other destinations.

As indicated in Section 6.2, the TMP will rely on the ASTP Advanced Studies, Concepts and Tools Program for key products (e.g., study results, models, etc.) in support of ongoing program integration, planning and management.

7.3.2 TMP Element Programs

FY’05 will be a transition year in which various programs are integrated as parts of Human and Robotic Technology, including the Technology Maturation Program (TMP). The President’s Vision for Space Exploration (February 2004) is the framework for technology development conducted within the Office of Exploration Systems. Work conducted within the Technology Maturation Program shall be aligned with the Nation’s Exploration Vision and all Program Operating Plan submittals responding to this Guidelines Letter shall be so aligned. Specific traceability to the Exploration Vision shall be incorporated into POP responses to clearly indicate the alignment of the same to this Vision.

The several Element Programs within the TMP are the following:

- High Energy Systems Technology Program
- Space Platforms and Systems Technology Program
- Space Operations Technology Program
- Lunar and Planetary Surface Operations Technology Program
- In-Space Technology Experiments Program

All of these element programs will be formulated in close coordination with each other, and with other NASA and non-NASA technology developments to assure rapid, cost-effective development and validation of novel approaches for future human and robotic space exploration. The following sections summarize each of these major elements. Work conducted within the TMP shall be aligned with the Exploration Vision (February 2004) and all OExS POP guidelines (March 2004). All planning, including POP inputs shall be so aligned. Specific traceability to the Exploration Vision shall be incorporated into POP responses to clearly indicate the alignment of the same to this Vision.

7.3.3 TMP Planning Leadership¹⁹

Program formulation for the several TMP Element Programs will be led by a single program manager at NASA Headquarters, with the support of a NASA Center-based planning team, drawn from the Field Centers with competency/expertise appropriate to the technical areas involved. Program Elements are subdivided into Projects, Sub-Projects and Tasks. The planning team will provide Program Element plans including milestones, budgets, work force and facility requirements by June 1, 2004 to the TMP Program Director, who will incorporate them into integrated H&RT planning (consistent with this formulation plan).

TMP Approval Authority. The overall TMP plan will be subject to the review and concurrence of the Deputy Director for H&RT, Development Programs Division (OExS) and the review and approval of the Director, Development Programs Division. The several Element Program plans will be subject to the review and concurrence of the Program Director, Advanced Space Technology Program, and the review and approval of the Deputy Director for H&RT, Development Programs Division (OExS). Details concerning TMP program formulation and planning leadership information are provided in Appendix I.

7.3.4 High Energy Systems Technology Program

This program will examine a range of key technology options associated with future space exploration systems and architectures that are ‘energy rich’—including high power space systems, highly efficient and reliable space propulsion systems, and the

¹⁹ Note: the Program Formulation leadership approach outlined here is an update from the original concept provided in the OExS POP Guidelines (See Appendix D). The plan presented here supercedes the earlier approach.

storage, management and transfer of energy/propellants in space. It may also address (as appropriate) high-energy maneuvering; including aero-entry, aero-braking, and other aero-assist related R&D. Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration. The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

In addition, this program will (where appropriate) pursue intensive, nearer-term development and validation of advanced technology alternatives to ‘baseline’ technology selections within major exploration projects implementing design and advanced development efforts. Technology projects related to advanced electrical power generation, management and electric propulsion will be formulated in close coordination with OExS Project Constellation, Project Prometheus, the Office of Space Science In Space Power and Propulsion Program, and other relevant programs.

This is a new Element Program; it will involve both competitively selected, extra-mural technology development projects, as well competitively selected intra-mural technology development projects. The High Energy Space Systems Technology Program will be developed in accordance with this H&RT Program Formulation Plan.

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ will take responsibility for delivery of the appropriate products.

Technical Themes. The HESS technology program will develop and demonstrate a range of key new capabilities for human/robotic space exploration.²⁰ These demonstrations may involve either a single new subsystem/system (e.g., a new approach to power generation and management) or the validation of several new systems in a larger, higher-fidelity demonstration or test bed. Major HESS technical themes include the following:

- **High-Efficiency, Low-Mass Solar Power Generation Systems.** This theme will include integrated development and demonstration of high-power, low-mass photovoltaic solar arrays, modular intelligent power management and distribution systems, etc.; other topics may include novel systems approaches including thermophotovoltaic systems, solar dynamic systems, or other concepts. R&D

²⁰ Note that technology developments within the Technology Maturation Program will complement current and future investments that fall within the responsibility of Project Prometheus, the nuclear systems initiative. More generally, investments within ASTP, TMP and ITTP will be closely coordinated with R&D within Project Prometheus—and the In-Space Power and Propulsion Program within the NASA Office of Space Science—but will not address topics already covered by other programs.

may also address development and validation of related cryogenic cooling and thermal management systems.

- **Highly-Reliable/Autonomous Deep-Space Cryogenic Propellant Refueling Systems.** This theme will involve the development and validation of systems-technologies to enable extremely low-/zero- boil-off cryogen storage (involving light-weight tankage, fluid management, highly-effective insulation, active cooling and thermal management, etc.).
- **High- Efficiency/Power and Low-Mass Electromagnetic (EM) Propulsion Systems.** This theme will pursue the integrated development and demonstration of individual high-power EM propulsion as well as operational validation of ‘clusters of thrusters’ to achieve high power, as well as supporting power management and distribution systems. R&D may also address development and validation of related thermal management systems.
- **Deep-Throttling Multi-Use In-Space Cryogenic Engines.** This theme will include development and demonstration of key operational performance characteristics of a range of new space engines, compatible with future use of *in situ* resources.
- **Novel High-Energy Space Systems Demonstrations.** This theme will enable the development and validation of highly novel new technologies that have the potential to enable major, systems-of-systems level innovations concerning high-energy space systems

These themes should be used to guide the formulation of the High Energy Space Systems (HESS) Technology Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.3.5 Space Platforms and Systems Technology Program

The Advanced Space Systems and Platforms Technology Program will examine a range of key technology options associated with future space exploration systems and architectures that are resilient, reliable and reconfigurable through the use of miniaturization, modularization of key functions in novel systems approaches. Platforms technologies that support self-assembly and in-space assembly, as well as in-space maintenance and servicing will be included. These efforts will be closely coordinated with in-space assembly and related R&D within the Space Operations Technology Program (e.g., involving extra-vehicular activity (EVA) systems, robotics, etc.). (See Section 6.3.6.) Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration.

The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

In addition, this program will (where appropriate) pursue intensive, nearer-term development and validation of advanced technology alternatives to ‘baseline’ technology selections within major exploration projects implementing design and advanced development efforts. Technology projects related to humans-in-space systems (e.g., habitation systems) will be formulated in close coordination with NASA’s Office of Biological and Physical Research, and other relevant programs; while those related to Earth orbiting platforms will be formulated in coordination with the NASA Office of Earth Science and other relevant programs.

This is a new Element Program; it will involve both competitively selected, extra-mural technology development projects, as well competitively selected intra-mural technology development projects. The Advanced Space Systems and Platforms Technology Program will be developed in accordance with the H&RT Program Formulation Plan (see above).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ will take responsibility for delivery of the appropriate products.

Technical Themes. The Advanced Space Systems & Platforms (ASSP) Technology Program will develop and demonstrate a range of key new capabilities for human/robotic space exploration. The formulation and later execution of this element program will be pursued in close coordination with related programs within H&RT, as well as within the Office of Biological and Physical Research. Major ASSP technical themes include the following:

- **Intelligent Modular Systems.** This technology theme will involve development and demonstration of a range of reconfigurable, modular space subsystems, systems and systems of systems and others.
- **Robust & Reconfigurable Habitation Systems.** This theme will pursue the integrated demonstration of novel habitat concepts with other key subsystems such as life support, environmental monitoring and control, radiation protection, and others.
- **Integrated System Health Management (ISHM).** This technology theme will involve integrated development and validation of sensors, software and computing to enable the monitoring and management of diverse subsystems/systems within future exploration vehicles and systems of systems.
- **Communications Networks and Systems.** This theme includes the development and integrated demonstration of novel high-bandwidth communications systems

(including RF and optical communications approaches, supporting data processing/compression and software); also including demonstration of wireless and other approaches to local area and intra-vehicle network communications within the context of modular space systems architectures.

- **Novel Platform Systems Concept Demonstrations.** This theme will enable the development and validation of highly novel new technologies that have the potential to enable major, systems-of-systems level innovations related to traditional platform functions.

These themes should be used to guide the formulation of the Advanced Space Systems & Platforms (ASSP) Technology Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.3.6 Space Operations Technology Program

This program will examine a range of key technology options associated with future space exploration systems and architectures that involve a variety of combinations of advanced robotic and human capabilities, ranging from remotely tele-supervised robotic systems, through locally-teleoperated systems, to focused human presence (with robotic agent assistance). Technologies that enable in-space assembly, maintenance and servicing will be included. Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic space exploration in support of the U.S. Vision for Space Exploration. The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs.

These efforts will be closely coordinated with spacecraft subsystem, system, and related R&D within the Space Platforms and Systems Technology Program. (See Section 6.3.5.) The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

In addition, this program will (where appropriate) pursue intensive, nearer-term development and validation of advanced technology alternatives to ‘baseline’ technology selections within major exploration projects implementing design and advanced development efforts. Technology projects related to humans-in-space systems (e.g., extravehicular activity (EVA) systems) will be formulated in close coordination with NASA’s Office of Biological and Physical Research, and other relevant programs.

This is a new Element Program; it will involve both competitively selected, extra-mural technology development projects, as well competitively selected intra-mural

technology development projects. The Advanced Space Operations Technology Program will be developed in accordance with this H&RT Program Formulation Plan.

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the 'program formulation team' will take responsibility for delivery of the appropriate products.

Technical Themes. The Advanced Space Operations (ASO) Technology Program will be planned and implemented in close coordination with the ASSP Technology Program (described above); this will involve coordinated development of interfaces and interface standards, and may also involve jointly sponsored major demonstrations. Major ASO technical themes include the following:

- **Space Assembly, Maintenance and Servicing Systems.** This theme will involve advanced robotic systems, ranging from autonomous (tele-supervised) systems, to tele-presence systems, to robotic assistants to astronautics (EVA and IVA); including capabilities for autonomous identification, remove and replacement of failed systems elements as well as the reconfiguration of subsystems and/or systems as needed.
- **Extravehicular Activity (EVA) Systems.** This technology theme will involve the development of new EVA systems concepts and the integrated validation of all critical subsystems of a new EVA system, including garment, gloves, portable life support system (PLSS), portable power systems, and others.
- **Intelligent and Affordable On-Board Operations Systems.** This theme will involve development and integrated demonstration of major new concepts of operations, with particular emphasis on decreasing the dependence of future space exploration systems on human-in-the-loop based control approaches.
- **Reliable and Responsive Ground Operations Systems.** This technology theme will address both 'mission control' type operations as well as payload processing and launch type operations.
- **Novel Space Operations Demonstrations.** This theme will enable the development and validation of highly new technologies that have the potential to enable major, systems-of-systems level innovations, including highly autonomous deep space flight operations.

These themes should be used to guide the formulation of the Advanced Space Operations (ASO) Technology Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.3.7 Lunar and Planetary Surface Operations Technology Program

The Lunar and Planetary Surface Operations Technology Program will examine a range of key technology options associated with future lunar and planetary surface exploration and operations for a range of increasingly-ambitious human and robotic mission options through the development of in situ resource utilization technologies, highly-capable surface mobility systems, and various supporting infrastructures. Key objectives will derive from the goals of safe/reliable, affordable and effective future human and robotic lunar and planetary surface exploration in support of the U.S. Vision for Space Exploration.

The program will involve technology development, ground test beds and demonstrations, and—where appropriate—technology flight experiments and demonstrations as needed to establish the readiness of new system and architecture concepts for adoption within future human and robotic exploration studies and programs. The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

In addition, the program will (where appropriate) pursue intensive, nearer-term development and validation of advanced technology alternatives to ‘baseline’ technology selections within major exploration projects implementing design and advanced development efforts. Technology projects related to remotely supervised, surface robots (e.g., ‘rovers’) will be formulated in close coordination with NASA’s Office of Space Science, and other relevant programs.

This is a new Element Program; it will involve both competitively selected, extra-mural technology development projects, as well competitively selected intra-mural technology development projects. The Lunar and Planetary Surface Operations Technology Program will be developed in accordance with this H&RT Program Formulation Plan.

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ will take responsibility for delivery of the appropriate products.

Technical Themes. The Lunar & Planetary Surface Operations (LPSO) Technology Program will be planned and implemented in close coordination with the ASSP Technology Program (described above); this will involve coordinated development of interfaces and interface standards, and may also involve jointly sponsored major demonstrations. Major LPSO technical themes include the following:

- **Intelligent & Agile Surface Mobility Systems.** This theme will involve both unpiloted (locally and remotely controlled) and piloted mobility systems, with options ranging from exceptionally small systems (less than 1 kg total mass) to exceptionally large systems (greater than 10,000 kg total mass).
- **In Situ Resource Utilization Systems.** This technology development and validation theme will address excavation and handling of surface raw materials, extraction and processing of desired materials, and the production and

‘containerization’ of finished materials. This area also includes the collection and processing of gasses (e.g., the atmosphere of Mars).

- **Surface Manufacturing and Construction Systems.** This technology theme will incorporate the use of both ‘imported’ and indigenous materials in local manufacturing and construction.
- **Surface Environmental Management Systems.** This theme will pursue integrated systems approaches to the management of thermal, dust and chemical environments for both human and robotic explorers.

These themes should be used to guide the formulation of the Lunar & Planetary Surface Operations (LPSO) Technology Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.3.8 In-Space Technology Experiments Program

The In-Space Technology Experiments Program (In-STEP) will pursue both low- to mid- TRL flights of novel technologies, where appropriate, in addition to supporting the development and deployment (where required) of key infrastructures and carriers for such technology flight experiments (TFEs). The In-STEP effort will engage not only the other element programs within the H&RT Technology Maturation Program, but also possible TFEs emerging from the Advanced Space Technology Program and a range of other key technology options associated with future human and robotic space exploration and operations. Key objectives will derive from the goal of technology validation in support of safe/reliable, affordable and effective systems and missions in support of the U.S. Vision for Space Exploration. The program will involve TFE definition studies, accommodations planning and development (if needed), TFE development, and eventually flight on a range of carriers (including the International Space Station). The program will be formulated to support focused investments that systematically validate and/or invalidate key technologies and design concepts that might transform how the U.S. will pursue future space exploration goals.

In addition, this program will (where appropriate) pursue nearer-term testing of advanced alternatives to ‘baseline’ technology selections within major exploration projects advanced development efforts. Technology Flight Experiment projects (including accommodations) will be formulated in close coordination with NASA’s New Millennium programs, other U.S. government agencies, and other relevant programs.

This is a new Element Program; it will involve both competitively selected, extra-mural technology development projects, as well competitively selected intra-mural technology development projects. The In-Space Technology Experiments Program (In-STEP) will be developed in accordance with the H&RT Program Formulation Plan (see above).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the ‘program formulation team’ will take responsibility for delivery of the appropriate products.

Technical Themes. The InSTEP program will enable the timely identification, development and flight of important experiments (at TRL 5 or lower) in space to validate novel technology applications, as well as occasional larger-scale and/or higher fidelity demonstrations incorporating multiple technologies in new, interdisciplinary systems concepts. In general, InSTEP will work in close concert with other H&RT programs, providing flight opportunities for lower TRL technologies emerging from the ASTP, as well as defining and flying TFEs related to technology maturation efforts that are cross-cutting in character. Major InSTEP technical themes include the following:

- **Technology Flight Experiment (TFE) Definition.** This theme will address the array of technology disciplines incorporated within the H&RT family of programs ASTP, TMP and ITTP).
- **Technology Flight Experiment Accommodations.** This technical theme will include assessments of carriers, launch opportunities, and preliminary planning for in-space accommodation of TFEs.
- **Technology Flight Experiment Development.** This technical theme will address lower TRL technology flight experiments that may emerge from the ASTP, as well as cross-cutting TFEs related to developments within the TMP.
- **Technology Flight Experiment Integration, Launch and Operations.** This technical theme will include activities related to the integration, launch and operation of future H&RT technology flight experiments.

These themes should be used to guide the formulation of the In-Space Technology Experiments Program (InSTEP). The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific ‘projects’ within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes. In addition, this Element Program should be planned to be consistent with planning, already underway, in related areas of SBIR topics/subtopics for 2004.

7.3.9 TMP Resources Planning

Details concerning resources planning are provided in the OExS POP Guidelines. Unallocated funding in FY05 and out years has been used to establish a new funding line called “Competitive Opportunities” within each Program Element. This funding will be used for the competitive selection of future work so that the technical content of each Element is realigned with H&RT objectives.

In both POP responses and the Element Program Plans, Civil Service Full-Time Equivalents (FTEs) and on-site contractor Work-Year Equivalents (WYEs) will be identified. Overall, all budget discussions will be conducted in full cost. All full cost budgets at the sub-project level and above will be discussed in terms of direct

(procurement, direct civil service workforce, salaries, benefits, travel, service pools); and G&A. Management staffing is estimated as roughly 5% of the overall budget and is allocated proportionally to each Project.

Funding for SBIR/STTR proposal evaluators and Contracting Officer's Technical Representatives (COTRs) will not be included in the SBIR/STTR Program Management Budget. Where appropriate, resources to cover these costs should be included in the associated Technology Maturation Program Element.

7.4 Innovative Technology Transfer Partnerships

The Innovative Technology Transfer Partnerships (ITTP) comprises (1) technology transfer activities, (2) NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs. The FY2004 budget terminated the Commercial Technology Program. Under the cognizance of technology transfer activities, the program will continue to document and license technologies and make them available to the private sector as legislatively mandated and prudently manage NASA's intellectual property.

During the FY 2004 H&RT formulation process, the ITTP will undertake the development of integrated, multi-year planning, both at the ITTP level and for each of the several Element Programs. In addition, the ITTP will examine innovative options for the identification, selection and execution of future projects within each program area.

ITTP Approval Authority. The overall ITTP plan will be subject to the review and concurrence of the Deputy Director for H&RT, Development Programs Division (OexS) and the review and approval of the Director, Development Programs Division. The several Element Program plans will be subject to the review and concurrence of the Program Director, Innovative Technology Transfer Partnerships Program, and the review and approval of the Deputy Director for H&RT, Development Programs Division (OexS).

Details concerning program formulation and planning leadership information are provided in Appendix I. It is expected that the Headquarters program manager and supporting members of the program formulation team that will take responsibility for delivery of the appropriate products.

7.4.1 Technology Transfer Technical Themes.

The Technology Transfer (TT) Program supports the timely transfer of technology into and out of the full suite of NASA's applied research, technology and development programs. Major TT technical themes include the following:

- **NASA Field Center Technology Transfer Offices.** This technical theme primarily addresses the establishment and maintenance of key working relationships between ITTP and Field Center level mission managers, their supporting personnel, and Field Center strategic planners, as well as brokering negotiations of agreements for transfer of technology into or out of the Agency.

- **Regional and National Technology Transfer Centers.** This theme primarily addresses the targeted identification, establishment, and maintenance of relationships between ITTP and industry potentially leading to collaborations with NASA for transfer of technology into or out of the Agency, as well as supporting ITTP's brokering of resulting partnerships by providing industry sector-specific and other commercial perspective.
- **NASA Intellectual Property (IP) Efforts.** This theme support NASA efforts to protect and license Agency innovations and intellectual property.
- **Special Technology Transfer Projects.** This theme will involve any special projects as they may arise related to seeking innovative approaches to improve the infusion of new technologies into NASA's diverse programs. This theme also includes specific 'outreach' activities, such as publications and databases (e.g., Innovation magazine, NASA TechBriefs, etc.).

These themes should be used to guide the formulation of the Technology Transfer Agents (TTA) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

7.4.2 Small Business Innovation Research (SBIR) Technical Themes.

The Small Business Innovation Research (SBIR) Program provides an opportunity for small business-based innovators to become involved with NASA's R&D investment portfolio. SBIR serves the interests of all of NASA strategic Enterprises. Major SBIR technical themes include the following:

- **Technologies to Enable Human and Robotic Exploration.** This theme will involve those technologies needed for direct human and robotic exploration of our Solar System (i.e., the Moon, Mars and the other planets, moons and small bodies), and for remote observation-based exploration (such as the astronomical search for origins).
- **Technologies to Advance Earth System Science and Understanding of the Sun-Earth Connection.** This technical theme will involve technologies needed for both Earth orbiting and deep space missions, and other activities related to Earth system science and the Sun-Earth connection.
- **Technologies to Improve U.S. Aviation Systems and Operations.** This theme will involve both aircraft systems research and technology and air traffic control systems research and technology.

These themes should be used to guide the formulation of the Small Business Innovation Research (SBIR) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. The themes are inclusive of any

related educational activities. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

7.4.3 Small Business Technology Transfer (STTR) Technical Themes.

The Small Business Technology Transfer (STTR) Program provides an opportunity for advanced technologies and new concepts to be transitioned more effectively and more rapidly from the university community to small business-based innovators and then to NASA's R&D investment portfolio. STTR serves the interests of all of NASA strategic Enterprises. Major STTR technical themes include the following:

- **Technologies to Enable Human and Robotic Exploration.** This theme will involve those technologies needed for direct human and robotic exploration of our Solar System (i.e., the Moon, Mars and the other planets, moons and small bodies), and for remote observation-based exploration (such as the astronomical search for origins).
- **Technologies to Advance Earth System Science and Understanding of the Sun-Earth Connection.** This technical theme will involve technologies needed for both Earth orbiting and deep space missions, and other activities related to Earth system science and the Sun-Earth connection.
- **Technologies to Improve U.S. Aviation Systems and Operations.** This theme will involve both aircraft systems research and technology and air traffic control systems research and technology.

These themes should be used to guide the formulation of the Small Business Technology Transfer (STTR) Program. The themes represent the technical areas that must be considered in developing the element program plan, but may or may not reflect eventual specific 'projects' within the element program. The themes are inclusive of any related educational activities. For example, a future project—yet to be defined—might address one, two or several of these technical themes.

7.5 Links to Strategic Planning and Road Maps

As noted in Section 4.3, the success of H&RT formulation process will require the successful integration and focusing of ongoing programs in the areas of ASTP and ITTP and their synthesis with future TMP Maturation Programs beginning in FY 2005. The ASTRA ("Advanced Systems, Technologies, Research and Analysis) Road Maps will provide a key framework around which the programmatic aspects of the transition may be organized. In each of the several paragraphs above concerning specific Element Programs within ASTP and TMP, suggestions are made for reference material within the ASTRA road mapping system.

A central aspect of the Formulation Plan will be development of an explicit 'trace' from the goals and objectives of the H&RT Theme as documented in the Agency Integrated Budget and Performance Documents (IBPDs) to both the current and planned programs. This will include examination of initial key metrics for the Theme, as

documented during the FY 2005 budget formulation process, and identification of how the programs may support satisfaction of these metrics.

Major program-related Formulation Plan products will include:

- Program Operating Plan (POP) Guidelines to the NASA Field Centers;²¹
- Detailed plans for all major programs (including SBIR and Center planning);
- ASTRA Road Maps for FY 2004; and,
- Additional program-related products, including MOAs, inputs to the development of an H&RT Integrated Technology Plan (ITP; by September 2004), etc.

²¹ These were provided on 16 March 2004; a copy of relevant H&RT text is provided in Appendix D.

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Section 8

H&RT Project Formulation and Acquisition Planning

NOTE: ALL INFORMATION PROVIDED IN THIS SECTION CONCERNS GENERAL PLANNING FOR H&RT. THIS INFORMATION--WHEREVER APPROPRIATE--IS SUPERCEDED BY H&RT BAA 04-02.

8.1 Introduction

The following section provides information concerning the formulation of specific projects within the two H&RT Programs: the Advanced Space Technology Program (ASTP) and the Technology Maturation Program (TMP).²²

Following the release of this Formulation Plan (31 March 2004), the immediate priority within affected H&RT programs and teams will be on the initial formulation of key program plans (see Section 4). In addition, during FY 2004, two important project formulation efforts will be undertaken:

- Release of an NASA Broad Agency Announcement (BAA) to identify extramural technology projects, consistent with the new program plans being formulated, and
- Implementation of an initial NASA-internal competitive announcement, to identify intramural technology projects, consistent with the new program plans being formulated.

All H&RT project formulation and acquisition planning will be closely coordinated with overall Office of Exploration Systems program efforts and Acquisition planning. As a minimum, during the period from March 2004 through March 2005, all H&RT project formulation efforts will be closely coordinated with other Code T efforts to assure that the NASA technical community provides all needed support to the initiation of Project Constellation.

8.2 H&RT Projects Approach Overview

Within the several H&RT programs (ASTP, TMP and ITTP), technology research, development and validation efforts will be executed through several Element Programs (see Section 6). Within each Element Program, a family of well-coordinated technology projects shall be established—each focused on resolving some systems-of-systems level problem and/or addressing a critical, sub-system level technology gap or opportunity. These technology projects will involve both extramural and intramural efforts and shall be established through competitive processes (see discussion below). Moreover, once established, the individual projects (and the higher-level H&RT Element Programs) will be executed in accordance with Earned Value Management System (EVMS) practices. (See Appendix G.)

²² The information provided in this section does not affect the formulation of projects within the SBIR and STTR programs of the ITTP; these will continue to be formulated consistent with existing ITTP practices.

Details concerning the characteristics of typical projects are still being developed (03 April 2004). It is expected that the general character of SBIR and STTR projects will be largely unchanged (although some adjustments are possible). However, it is expected that all new projects within ASTP and TMP will follow a standard template that will allow (a) a more effective integration of the ‘cycles of innovation’ with the development spirals for future systems; (b) a ready approach to enable the application of EVMS and related management practices to H&RT; and, (c) the implementation of the concept of a more DARPA-like approach to space technology R&D at NASA (including a system for conducting highly-competitive, ‘program-focused’ technology development). Figure 7-1 illustrates the expected life cycle of a project within either ASTP or TMP.

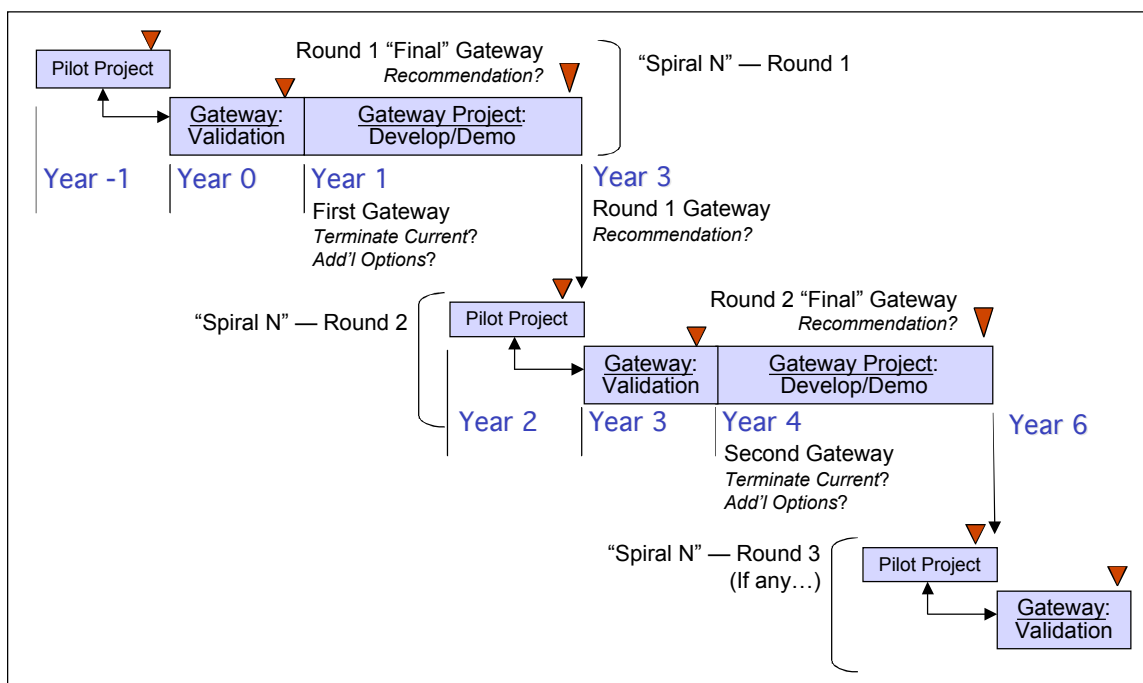


Figure 8-1 Typical Life Cycle of a Technology Project within HR&T

Additional details concerning details of the structure of H&RT projects (intramural and extramural, ASTP and TMP and ITTP) will be provided in a future update of this initial Formulation Plan. The following paragraphs provide initial guidance concerning the anticipated scope, number, duration, and other key aspects of projects to be established.

8.3 Advanced Space Technology Program (ASTP) Projects

8.3.1 ASTP Extramural Projects: Competitive BAA Process

During Summer 2004, a BAA will be released to solicit the initial round of ‘extramural’ NASA research, technology development and demonstration projects for

ASTP within H&RT. The general characteristics of these projects are described in H&RT BAA 04-02.

8.3.2 ASTP Intramural Projects: Competitive Selection Process

During the late Spring 2004, an internal, directed invitation has been released to solicit the initial round of 'extramural' NASA research, technology development and demonstration projects for ASTP within H&RT. The detailed characteristics of these projects were described in the H&RT Intramural Call for Proposals (ICP).

Proposals submitted in response to this ICP must describe a complete 2-phase research and development (R&D) plan. However, a key product of the first phase of each selected project will be a detailed plan for the implementation of the remainder of the project.

Initial awards under this ICP will be for Phase I R&D for no longer than 12 months, and will typically range from 10-15% of the total cost of the full project. Only the most promising Phase I projects will be selected for continuation to Phase II, an additional funding period for the completion of the project. Continuation at the end of Phase I will be contingent upon availability of funds and adequate progress toward project progress milestones as determined by NASA management.

8.4 Technology Maturation Program (TMP) Projects

8.4.1 TMP Extramural Projects: Competitive BAA Process

During Summer 2004, a BAA will be released to solicit the initial round of 'extramural' NASA research, technology development and demonstration projects for TMP within H&RT. The general characteristics of these projects are described in H&RT BAA 04-02.

8.4.2 TMP Intramural Projects: Competitive Selection Process

During the late Spring 2004, an internal, directed invitation has been released to solicit the initial round of 'intramural NASA research, technology development and demonstration projects for TMP within H&RT. The characteristics of these projects were described in the H&RT ICP.

8.5 Innovative Technology Transfer Partnership (ITTP) Projects

During FY 2004, an extended re-planning and reformulation process will be implemented for various Innovative Technology Transfer Partnership programs and projects. This process will include the ongoing implementation of a competitive Request for Proposals (RFP) for the SBIR and STTR programs within ITTP. Following completion of these reformulation efforts, during FY 2005, new approaches for identifying and selecting future ITTP projects will be developed and implemented. These approaches will be documented in a future version of the H&RT Formulation Plan.

Section 9

Schedule and Major Milestones

A highly ambitious schedule has been established for this Formulation Plan, based on the challenges within the new U.S. Exploration Vision, and the dictates of the annual Federal Budget cycle. This schedule for this Formulation Plan is summarized in Table 9-1.

The overall schedule is driven by the need for H&RT to support key milestones for Code T during FY 2004, leading into the beginning of a successfully integrated and realigned program in FY 2005. The commitments at the OExS-level which H&RT must fulfill during FY 2004 include: (1) development of an integrated road map for human and robotic technology investments, consistent with the President's Vision for Space Exploration; (2) incorporation into that road map of an integrated view of technology-related programmatic risks, and a resulting risk mitigation plan; (3) a detailed plan for realignment of ongoing programs, as may be appropriate; and (4) focused planning for the Technology Maturation Program, beginning in FY 2005, and including inputs to the FY 2006 and out-year planning process.

FY 2004 H&RT Schedule of Major Milestones
[Version: 29 July 2004]

Month	Milestone	Status
March	Complete Independent Review / Initial Report (WB&B)	Complete ~3/1
	Issue H&RT POP Guidelines to NASA Centers (OExS)	Complete ~ 3/16
	Form NASA HQ H&RT Management Team	Complete ~ 3/26
	Issue H&RT Programs Formulation Plan (Planned 4/1)	Complete ~ 4/5
April	2-Day Retreat on Acquisition Strategy (Code TD)	Complete ~ 4/1
	H&RT Formulation Kick-Off Video Conference (H&RT)	Planned (4/6)
	OExS Face-to-Face with Center POCs at HQ	Planned (4/9)
	Form NASA-wide H&RT Leadership Team	Planned (4/1-14)
May	H&RT Element Program Plans due to Code TD - DRAFT	Complete 6/1
	ASTP, TMP Intramural Cal for Proposals (ICP)	Planned (5/21)
	Center H&RT ICP Proposals Due	Complete (6/16)
	Center H&RT Initial POP Inputs Due (In-Guidelines)	Planned (6/08)
	H&RT Programs (Draft) Office Work Instructions	Planned (5/31)
June	NASA Center ASTP, TMP ICP Proposals Due	Planned (6/21)
	Center H&RT Final POP Inputs Due (with Over-guidelines)	Complete (6/21)
	H&RT Strategic Status Briefing to OExS AA	Complete
	OExS Submit due to Code B (via NBS)	Complete (6/30)
July	FY'04 H&RT Initial NASA Brad Agency Announcement (04-02)	Complete (7/28)
	Enterprise Resource Mgt Offices Briefings to Code B	Plan (7/2-4)
	NASA Comptroller Reviews with Enterprises	Plan (7/12-14)
	OExS Preparation for Briefings to Executive Council on '06	Plan (7/15-16)
	Select Intramural Projects to start in FY'05	Complete (7/19)
	OExS Briefings to Executive Council on '06 Budget	Plan (7/23-27)
August	Executive Council '06 Brief & Recommendation to Administrator	Plan (7/30-8/2)
	NASA Administrator '06 Budget Decisions	Plan (8/5-6)
	FY'04 H&RT Initial BA 04-02 - Notices of Intent Due	Plan (See BAA)
September	FY'04 H&RT Initial NRA - Proposals Due	Plan (See BAA)
	NASA '06 Budget to OMB	Plan (9/6-10)
	NASA '06 Budget Briefings to OMB	Plan (9/13-24))
October (FY'05)	Begin FY'05 NASA/OExS/H&RT Intramural Programs	Plan (10/1)
	Begin H&RT FY'06 Program Formulation Cycle	Plan (10/1)
	H&RT Element Program Plans FY ' 05 FINAL	Planned (10/31)
	Announce FY'05 H&RT BAA 04-02 Projects (ASTP/TMP)	Planned (10/31)

Table 9-1 Integrated Human and Robotic Technology Programs Planning Schedule and Major Milestones for FY 2004

Section 10

Resources

The following section documents the resources that will be needed to achieve successfully to goals and objectives of this H&RT programs Formulation Plan.²³ Key 'resources' for the success of this plan including (1) availability of detailed personnel from the Office of Space Flight (Code M) and the Office of Aeronautics (Code R) to support H&RT activities during the transition period; (2) full and focused support of NASA Field Center personnel in accomplishing all aspects of the formulation plan, ranging from initial program realignment planning within the POP process, to the completion of FY 2005 H&RT program plans; and, (3) appropriate and timely coordination and support with/from other NASA Headquarter personnel.

At this time (03April04), no additional resources have been identified that might be made available to provide unique funds from NASA HQ to support Field Center personnel labor, travel or other costs in support of this program formulation process. Because of the extraordinary circumstances involved with the announcement of the new U.S. Vision for Space Exploration, a fast-paced and flexible approach to 'resourcing' this activity within the Agency is necessary. NASA Field Centers are therefore suggested to apply FY'04 funds from ongoing MSMT and ITTP programs (wherever possible and appropriate), or Center/Corporate funds where necessary.

²³ Details regarding resources necessary to undertake the execution of H&RT programs within this Formulation Plan will be provided in the various volumes of H&RT planning to be developed during the next several months.

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Section 11

Formulation Risk Assessment and Mitigation Planning

The following are risks that have been identified that might impede the successful execution of this plan,²⁴ including an indication of the severity of EACH risk, as well as identification of mitigation strategies; they are:

- Independent Review Delays. Additional independent reviews are an important key in this plan; as a result, an important source of risk is the possibility that these reviews might not be completed in a timely way, or that it might not provide a sufficient set of data to support guidelines for ongoing programs.
 - Probability of Risk Occurring: Low
 - Impact if Risk is Realized: High
 - Mitigation Approach: Formulation plan anticipates timely collection and analysis of related data from existing and to-be-developed documents to complement independent review efforts.
- Staffing Action Delays. The plan depends upon timely action by NASA personnel to implement staffing actions for the H&RT formulation process; as a result, another important sources of risk is the possibility that these actions might be delayed, or that the computerized systems used to ‘screen’ applicants might fail to yield appropriate candidates in a timely way.
 - Probability of Risk Occurring: Moderate
 - Impact if Risk is Realized: High
 - Mitigation Approach: Close attention to timely responses from appropriate NASA Field Center or Headquarters offices to assure needed personnel area available.
- Cultural Challenges. Whenever there is substantial change in an organization or program is attempted, there is the real risk of cultural resistance on the part of the organizations and/or individuals who will be affected by the change. Often these ‘cultural challenges’ may be due to a lack of complete information about the planned changes or about new prospects that may emerge following the change. Such cultural resistance could deter or undermine the timely success of the transition for H&RT.
 - Probability of Risk Occurring: High
 - Impact if Risk is Realized: Moderate
 - Mitigation Approach: The Formulation Plan anticipates the requirement that reliable and timely information concerning decisions and the course of events must be provided to those who will be affected by the creation of the H&RT Theme. This communication will involve several forms, including person-to-person communications, site visits to key Field

²⁴ This section does not reflect the risks associated with the execution of the programs being formulated. Those risks will be addressed within the appropriate Program, Element Program and Project planning.

Centers (including presentations and Q&A sessions with appropriate personnel), and broadly distributed memoranda documenting plans, progress and any changes in plan.

- Center Realignment Planning Delays. Depending on the scope of needed changes in near-term planning to support the realignment of H&RT programs, there may be a requirement for additional time for NASA Field Centers to complete the initial round of planning during the Spring of 2004.
 - Probability of Risk Occurring: Moderate
 - Impact if Risk is Realized: Moderate
 - Mitigation Approach: In the event of significant delays in completing Center inputs, Program Formulation efforts may be continued in parallel with the planned release of an initial BAA for H&RT without affecting the subsequent due date for planning inputs to the FY 2006 budget process.
- Formulation Team Planning Delays. The tasks being assigned to the several H&RT element program managers and their supporting NASA Center-staffed formulation teams are significant. Depending on the scope of detailed planning within each group, the ‘chemistry’ of the group and/or the effectiveness of the individuals in each group, there may be delays in producing a strong ‘first full draft’ of the plan for each element (and thence for the major programs).
 - Probability of Risk Occurring: Moderate
 - Impact if Risk is Realized: High
 - Mitigation Approach: Firstly, the development of the Element Program Plans will be pursued in parallel—not in series—with the development of other key documents (such the intramural call for proposals or the planned extramural NASA Research Announcement). Minor delays in an individual team should not adversely affect the entirety of the effort. In addition, regular reviews (i.e., weekly) will be conducted across the several planning efforts to assure that any problems that may arise are uncovered and addressed as soon as possible.

Additional risks and mitigation strategies will be formulated as needed; future versions of the plan will include an assessment of risk results up to the date of the revision.

Section 12

Program Reviews and Evaluation

Consistent with the requirements of NASA Procedural Requirements (NPR 7120.5B), a Non-Advocate Review (NAR) will be completed prior to requesting approval for the program plan(s) to assure program planning quality and execution effectiveness. During Program Formulation the practices of quarterly status reviews (QSR) shall be initiated; QSRs will be continued from Project to Program during program/project execution, beginning in FY 2005. These reviews shall address: technical requirements and achievements; schedules; projected life cycle cost (LCC); related issues and concerns; EVMS and VMS plans and status; and, safety, security, environmental compliance; risk management plans and status; and, other program metrics.

In addition, the Associate Administrator for the Office of Exploration Systems has requested an independent review of H&RT program planning—with particular emphasis on prior MSMT program content. (25 March 2004; e-mail message, C. Steidle to distribution.) Details concerning the implementation of this, or other independent reviews will be provided in a future update of this document.

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Section 13

Summary

This Formulation Plan will result in the timely integration of various ongoing NASA space research and technology programs (including realignment where needed) with new program content under the H&RT Theme Technology Maturation Program. The Plan will result in the development of a comprehensive H&RT Integration Technology Plan (ITP) that will provide overarching direction to diverse H&RT activities over time, while informed suppliers and customers alike about the goals and objectives of the Theme.

This Formulation Plan provides for the establishment of a new organizational approach and a new headquarters management team to work with the several NASA Centers, external partners and others to achieve the technology goals and objectives of the U.S. Space Exploration Vision.

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Appendix A

Definitions

A.1 Glossary of Acronyms

A/D	Advanced Development (a.k.a., “TechMat” in the nomenclature of JSF Program Management)
APG(s)	(IBPD) Annual Performance Goal(s)
AMSC	Advanced Materials and Structural Concepts
ASCT	Advanced Studies, Concepts and Tools
ASPS	Advanced Space Platforms & Systems
ASTP	Advanced Space Technology Program
ASTRA	Advanced Systems, Technologies, Research and Analysis
ATLAS	Advanced Technology Life-cycle Analysis System
BAA	Broad Area Announcement
ASO	Advanced Space Operations
ASTP	Advanced Space Technology Program
CCEI	Communications, Computing, Electronics and Imaging
CICT	Computing, Information and Communications Technology (Program)
Code B	(NASA) Office of Budget
Code M	(NASA) Office of Space Flight (a.k.a., “OSF”)
Code R	(NASA) Office of Aerospace Technology (a.k.a., “OAT”)
Code S	(NASA) Office of Space Science (a.k.a., “OSS”)
Code T	(NASA) Office of Exploration Systems (a.k.a., “OExS”)
Code U	(NASA) Office of Biological and Physical Research (a.k.a., “OBPR”)
ConOps	Concept of Operations
CPI	(EVMS) Cost Performance Index
DARPA	Defense Advanced Research Projects Agency
DDR&E	Director, Defense Research and Engineering
DDT&E	Design, Development, Test and Engineering
DOD	Department of Defense
DOE	Department of Energy
ECS	Engineering for Complex Systems (Program)
ECT	Enabling Concepts and Technology (Program)
ETO	Earth-to-Orbit
EVMS	Earned Value Management System(s)

FTE	Full-Time Equivalent
G/Ls	Guidelines
GEO	Geostationary Earth Orbit
H&RT	Human and Robotic Technology
HESS	High Energy Space Systems
HLR	Human Lunar Return
IBPD	(NASA) Integrated Budget and Performance Document
ICP	(H&RT) Intramural Call for Proposals
InSTEP	In-Space Technology Experiments Program
IPA	Intergovernmental Personnel Assignment
ISO	International Standards Organization
ITAM	Integrated Technology Analysis Methodology
ITP	Integrated Technology Plan
ITTP	(H&RT) Innovative Technology Transfer Partnerships (Program)
JSF	Joint Strike Fighter
LEO	Low Earth Orbit
LLO	Low Lunar Orbit
LPSO	Lunar and Planetary Surface Operations
MOA	Memorandum of Agreement
MSMT	Mission and Science Measurement Technology (MSMT) Program
NAI	National Aerospace Initiative
NASA	National Aeronautics and Space Administration (a.k.a., “the Agency”)
NGLT	Next Generation Launch Technology
NPG	NASA Procedures and Guidelines
NR	Naval Reactors (an Organization within the U.S. Navy)
NRA	NASA Research Announcement
NRO	National Reconnaissance Office
NSF	National Science Foundation
NTP	NASA Technology Inventory
OMB	Office of Management and Budget
ONR	Office of Naval Research
OWI	(ISO) Office Work Instruction
PD	(NASA) Position Description
PEO	(Code T) Program Executive Officer
PgmMS	Program Management Schedule
PMS	Project Management Schedule
POP	(NASA) Program Operating Plan
PPCS	Power, Propulsion and Chemical Systems

Q&A	Question and Answer
QFD	Quality Function Deployment
QSR	Quarterly Status Review
R&D	Research and Development
R&D3	R&D Degree of Difficulty
SBIR	Small Business Innovation Research (Program)
SISM	Software, Intelligent Systems and Modeling
SPI	(EVMS) Schedule Performance Index
STT	Strategy-to-Task-to-Technology
STTR	Small Business Technology Transfer (Program)
TMP	(H&RT) Technology Maturation Program
TRL	Technology Readiness Level(s)
URETI	University Research Engineering and Technology Institute
WBS	Work Breakdown Structure
WYE	Work Year Equivalent Structure

A.2 Lexicon of Terms in Common Usage

The following are some terms of ‘common usage’ within the H&RT Formulation Plan and supporting processes.

This is the ‘first cut’ at this lexicon: the section will be updated as needed to resolve quickly any issues arising due to semantics and/or definitions during the formulation process.

Questions and/or suggestions concerning terms to be added or adjusted are invited.

A.2.1 General Terms

The following are some general terms expected to be in common usage.

“Risk”

- The probability of that an event will occur, multiplied by the consequences of the event occurring
- Note: For purposes of the H&RT Element Program Plans, risk includes both technological and programmatic risk.

“Component”

- The smallest discrete item in the context of a system (may change based on the system)
- Examples: a photovoltaic cell and/or blanket

“Subsystem”

- A distinguishable functional ‘unit’, comprising a number of components and typically subject to command/control in the context of a larger system
- Examples: a solar array, made of cells, blanket, local wiring, structure, etc.

“System”

- An relatively independent functional ‘unit’, comprising multiple subsystems and typically capable of largely independent command/control
- Examples: a typical spacecraft, a stand-alone ‘power plant’, a ‘rover’, an integrated habitat (including life support, etc.), etc.
- Note: Often there is also an ‘intermediate system’ in many large systems; for example, the ‘propulsion system’, the ‘power system’, etc.

“System-of-Systems”

- A coordinated collection of systems the collectively perform some higher-level function, comprising several discrete systems

- Examples: Global Positioning Satellite System, the set of inter-related systems that comprise the ‘surface capability’ for a lunar mission (e.g., lander, rover, EVA, etc.)

A.2.2 Technology Development Related Terms

“Technology Readiness Level”

- A discipline-independent ‘measure’ of the degree to which an individual technology (or set of technologies incorporated into a subsystem or system) are ‘ready’ for infusion into a system development effort.
- Note: *See the TRL White Paper indicated in the References.*

“Research and Development (R&D) Degree of Difficulty (R&D3)”

- A discipline-independent ‘measure’ of the expected probability of successfully achieving some individual technology R&D objective (or set of objectives)
- Note: *See the R&D3 Readiness White Paper indicated in the References.*

“Strategic Technical Challenges”

- “System-of-systems” level problems whose resolution could fundamentally change the nature, architecture, approach and capabilities of future exploration missions.
- Note: *Referenced as a section in the H&RT Program Formulation Plan.*

A.2.3 Element Program Formulation Related Terms

The following are terms associated with implement of the H&RT Element Program formulation process.

“Systems-of-Systems Level Impact”

- The term refers to the ‘level of impact’ that a specific technology investment should be expected to yield; in this case, the objective of the R&D would be to affect decisions at the ‘system’ and ‘system-of-systems’ (or ‘architecture’) level.
- Example: *Successfully developing and demonstrating the capability to perform safe and affordable in-space refueling could have a ‘system-of-systems level impact’ on future space exploration missions.*

“System Level Impact”

- The term refers to the ‘level of impact’ that a specific technology investment should be expected to yield; in this case, the objective of the R&D would be to affect decisions at the ‘subsystem’ and ‘system’ level.

- Example: *Successfully developing and demonstrating a robust, highly mobile new surface rover for crew transport could have a ‘system’ level impact on future space exploration missions.*

“Subsystem Level Impact”

- The term refers to the ‘level of impact’ that a specific technology investment should be expected to yield; in this case, the objective of the R&D would be to affect decisions at the ‘component and ‘subsystem’ level.
- Example: *Successfully developing and demonstrating a reliable and affordable Integrated Vehicle Health Management (IVHM) (a ‘subsystem’ within the larger vehicle system’ could have a ‘subsystem’ or ‘system’ level impact on future space exploration missions.*

“Technical Approach”

- Discipline-specific technical methods to address technical challenges. “How” a particular technical objective or set of objectives will be achieved. Methods could include demonstrations, laboratory or field experiments, facilities requirements, workforce competencies, modeling and analysis techniques, performance metrics, exit criteria, desired outcome objectives.

“Technology Opportunity”

- One of potentially many specific technology options available to address a particular Technical Approach. In other words, a statement of “which technology” might be developed, tested and evaluated. A particular technology opportunity could address common or similar technical approaches.

“Technological Risk”

- “Technological Risk” concerns the probability that a given set of ‘measurable technical objectives’ (i.e., ‘technology metrics’) will be achieved during research and development, and the variance from got

“Programmatic Risk”

- “Programmatic Risk” addresses the probability of successfully executing a portion of an Element Program Plan (e.g., a procurement), and the operational impact of realizing a less than fully successful outcome to that effort.

A.2.2 Requirements Related Terms

The following are some terms related to requirements that may be expected to be in common usage during the formulation process.

“Concept of Operations”

- Defines how architectural elements are prepared for operations and deployed; defines how those elements are operated to execute a set of mission goals and objectives. (Also known as “ConOps”.)

“Constraints”

- Programmatic or operational mandates that are levied on a program or mission.
- Examples: estimated budgets and/or schedules; partnerships; or any other restricting parameters. (Constraints should be identified for Level 0, Level 1 and Level 2 requirements).

“Level 0 Requirement”

- Provides Agency objectives and goals; mission statement; basis for functional decomposition; establishes boundaries for the Agency program.
- Example: *“NASA shall develop a new Crew Exploration System to provide crew transport for exploration missions beyond low Earth orbit.”*

“Level 1 Requirement”

- Provides measurable and quantifiable program goals; defines performance requirements, concept of operations, and success criteria; basis for functional decomposition to system level.
- Example: *“The Crew Exploration System shall provide the capability to transport personnel to and from the Moon with a total probability of loss of crew of less than XX%.”*

“Level 2 Requirement”

- Provides measurable and quantifiable project goals; defines performance and functional requirements at the system level; basis for functional decomposition to subsystem level.
- Example: *“The crew modular shall provide an atmospheric pressure of XXPSIA.”*

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Appendix B

Selected Bibliography and References

Aerospace Technology Enterprise Strategy (December 2003)

Published by NASA, Winter 2003; Developed by the NASA Office of Aerospace Technology, consistent with guidelines and oversight provided by Code B / Strategic Investments Division with inputs and comments by the several NASA Enterprises.

Earned Value Project Management (2nd Edition; 2000)

Written by Quentin W. Fleming and Joel M. Kappelman; Published by the Project Management Institute (Newtown Square, Pennsylvania).

NASA Office of Exploration Systems POP Call (March 2004)

Developed by the Office of Exploration Systems and published by NASA Office of the Comptroller.

NASA Procedural Requirements NPR 7120.5B (November 21, 2002)

NASA Program and Project Management Processes and Requirements; Published by the NASA Office of the Chief Engineer (Code AE) at NASA Headquarters.

NASA Procedural Requirements NPR 1000.3 (February 4, 2004)

The NASA Organization w/ Changes; "Office of Exploration Systems."

NASA Strategic Plan (January 2003)

Published by NASA, Winter 2002/2003 to accompany the President's NASA FY 2004 Budget; Developed by the NASA Office of the Comptroller (Code B), Strategic Investments Division with participation by the several NASA Enterprises.

OAT Mission & Science Measurement Technology Program/Project Plans (2001-2003)

Published by the NASA Office of Aerospace Technology and supporting NASA Field Centers; these documents provide the details plans for MSMT programs prior to the release of the 2004 Vision for Space Exploration.

Office of Exploration Systems Request for Information (21 April 2004)

Published online at Federal Business Opportunities (FBO). Office of Exploration Systems RFI 04-01
<http://www1.epo.gov/spg/NASA/GMSFC/POVA/NASA-SNOTE-040421-001/Synopsis.html>

President's FY 2005 Budget for NASA (February 2003)

Published by General Printing Office / White House Office of Management and Budget, Winter 2004.

President's Vision for Space Exploration (January 14, 2004)

Released by the White House, Office of the President, January 2004 to accompany the President's NASA FY 2005 Budget.

Research and Development Degree of Difficulty – A White Paper (2000)

Published by NASA/Office of Space Flight (author: J. Mankins) as white paper to provide an additional, technology discipline independent scale for assessing technology; the Research and Development Degree of Difficulty (R&D3) indicates the difficulty that may be anticipated in progressing through the TRLs for a given technical problem.

e-Mail Message to NASA Executive Council Members: “Requirements Levels”

From Theron Bradley (NASA Chief Engineer; Code D); 26 February 2004; providing definitions of Level 0, Level 1, etc., requirements.

Space Flight Enterprise Strategy (December 2003)

Published by NASA, Winter 2003; Developed by the NASA Office of Space Flight, consistent with guidelines and oversight provided by Code B / Strategic Investments Division with inputs and comments by the several NASA Enterprises.

Reducing the Time From Basic Research to Innovation in the Chemical Sciences ; A Workshop Report to the Chemical Sciences Roundtable (2003)

Published by National Academy of Sciences; The chapter of particular interest is entitled “DARPA’s Approach to Innovation and Its Reflection in Industry” by Lawrence H. Dubois.

Technology Readiness Levels – A White Paper (1995)

Published by NASA/Office of Space Access and Technology (Author: J. Mankins) as white paper to provide more detailed definitions and examples for the standard ‘technology readiness levels (TRLs).

Appendix C

Strategy-to-Task-to-Technology: Key Strategic References

The following appendix provides the text of key ‘strategic’ references that inform the development of a “Strategy-to-Task-to-Technology” (STT) approach for human and robotic technology. It includes the following information:

- National Space Exploration Vision (January 2004);
- Linkages to/from NASA Strategic Planning (FY 2005 Update); and,
- Office of Exploration Systems Role within NASA (Change 51 to NPR 1000.3; 15 January 2005)

Additional reference materials will be provided in future updates of this Formulation Plan.

C.1 National Space Exploration Vision (January 2004)

The following is the U.S. National Exploration Vision (announced in January 2004 by President George W. Bush).

A Renewed Spirit of Discovery: The President’s Vision for U.S. Space Exploration

Background

From the Apollo landing on the Moon, to robotic surveys of the Sun and the planets, to the compelling images captured by advanced space telescopes, U.S. achievements in space have revolutionized humanity’s view of the universe and have inspired Americans and people around the world. These achievements also have led to the development of technologies that have widespread applications to address problems on Earth. As the world enters the second century of powered flight, it is time to articulate a new vision that will define and guide U.S. space exploration activities for the next several decades.

Today, humanity has the potential to seek answers to the most fundamental questions posed about the existence of life beyond Earth. Telescopes have found planets around other stars. Robotic probes have identified potential resources on the Moon, and evidence of water—a key ingredient for life—has been found on Mars and the moons of Jupiter.

Direct human experience in space has fundamentally altered our perspective of humanity and our place in the universe. Humans have the ability to respond to the unexpected developments inherent in space travel and possess unique skills that enhance discoveries. Just as Mercury, Gemini, and Apollo challenges a generation of Americans, a renewed U.S. exploration program with a significant human component can inspire us—and our youth—to greater achievements on Earth and in space.

The loss of Space Shuttles Challenger and Columbia and their crews are a stark reminder of the inherent risks of space flight and the severity of the challenges posed by space exploration. In preparation for future human exploration, we must advance our ability to life and work safely in space and, at the same time, develop the technologies to extend humanity's reach to the Moon, Mars, and beyond. The new technologies required for further space exploration also will improve the Nation's other space activities and may provide applications that could be used to address problems on Earth.

Like the explorers of the past and pioneers of flight in the last century, we cannot today all that we will gain from space exploration; we are confident, nonetheless, that the eventual return will be great. Like their efforts, the success of future U.S. space exploration will unfold over generations.

Goals and Objectives

The fundamental goal of this vision is to advance U.S. scientific, security and economic interests through a robust space exploration program. In support of this goal, the United States will:

- Implement a sustained and affordable human and robotic program to explore the Solar System and beyond;
- Extend human presence across the Solar System, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and,
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Bringing the Vision to Reality

The Administrator of the National Aeronautics and Space Administration will be responsible for the Plans, programs, and activities required to implement this vision, in coordination with other agencies, as deemed appropriate. The Administrator will plan and implement an integrated, long-term robotic and human exploration program structured with measurable milestones and executed on the basis of available resources, accumulated experience, and technology readiness.

To implement this vision, the Administrator will conduct the following activities and take other actions as required:

1. Exploration Activities in Low Earth Orbit

Space Shuttle

- Return the Space Shuttle to flight as soon as practical, based on the recommendations of the Columbia Accident Investigation Board;
- Focus use of the Space Shuttle to complete assembly of the International Space Station; and
- Retire the Space Shuttle as soon as assembly of the International Space Station is completed, planned for the end of the decade;

International Space Station

- Complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners, planned for the end of this decade;
- Focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities and developing countermeasures; and,
- Conduct International Space Station activities in a manner consistent with U.S. obligations contained in the agreements between the United States and other partners in the International Space Station.

2. Space Exploration Activities Beyond Low Earth Orbit

The Moon

- Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the Solar System;
- Starting no later than 2008, initiate a series of robotic mission to the Moon to prepare for and support future human exploration activities;
- Conduct the first extended human to the lunar surface as early as 2015, but no later than the year 2020; and,
- Use lunar exploration activities to further science, and to develop and test new approaches, technologies, and systems, including use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations.

Mars and Other Destinations

- Conduct robotic exploration of Mars to search for evidence of life, to understand the history of the Solar System, and to prepare for future human exploration;
- Conduct robotic exploration across the Solar System for scientific purposes and to support human exploration. In particular, explore Jupiter's moons, asteroids and other bodies to search for evidence of life, to understand the history of the Solar System, and to search for resources;
- Conduct advanced telescope searches for Earth-like planets and habitable environments around other stars;
- Develop and demonstration power generation, propulsion, life support and other key capabilities required to support more distant, more capable, and/or longer duration human and robotic exploration of Mars and other destinations; and
- Conduct human expeditions to Mars after acquiring adequate knowledge about the planet using robotic missions and after successfully demonstrating sustained human exploration missions to the Moon.

3. Space Transportation Capabilities Support Exploration

- Develop a new crew exploration vehicle to provide crew transportation for missions beyond low Earth orbit;

- Conduct the initial test flight before the end of this decade to provide an operational capability to support human exploration missions no later than 2014;
- Separate to the maximum practical extent crew from cargo transportation to the International Space Station and for launching exploration mission beyond low Earth orbit
 - Acquire cargo transportation as soon as practical and affordable to support missions to and from the International Space Station; and
 - Acquire crew transportation to and from the International Space Station, as required, after the Space Shuttle is retired from service.

4. International and Commercial Opportunities

- Pursue opportunities for international participation to support U.S. space exploration goals; and
- Pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low Earth orbit.

C.2 Linkages to/from NASA Strategic Planning (FY 2005 Update)

The following section summarizes major linkages from NASA's Strategic Planning (as updated for the President's FY 2005 Budget for NASA) to elements Human and Robotic Technology (H&RT) addressed by this Formulation Plan.

<u>Goal 3</u>	<u>Create a more secure world and improve the quality of life by investing in technologies and collaborating with other agencies, industry, and academia.</u>
Objective 3.2	Improve the Nation's economic strength and quality of life by facilitating innovative use of NASA technology.
<i>Outcome 3.2.1</i>	<i>On an annual basis, develop 50 new technology transfer agreements with the Nation's industrial and entrepreneurial sectors.</i>
APG 4HRT6	Complete 50 transfers of NASA technologies, expertise or facility usage to the U.S. private sector, through hardware licenses, software usage agreements, or Space Act agreements.
APG 5HRT18	Complete 50 technology transfer agreements with the U.S. private sector for the transfer of NASA technologies, through hardware licenses, software usage agreements, facility usage agreements or Space Act Agreements.
<u>Goal 7</u>	<u>Engage the public in shaping and sharing the experience of exploration and discovery.</u>
Objective 7.1	Improve public understanding and appreciation of science and technology, including NASA aerospace technology, research, and exploration missions.
<i>Outcome 7.1.4</i>	<i>Engage the public in NASA missions, discoveries and technology through public programs, community outreach, mass media, and the</i>

	<i>Internet.</i>
APG 4HRT11	Publish and distribute program specific publications (Aerospace Innovations, NASA Tech Briefs, Spinoff) including 1 industry targeted edition, in a sector where NASA can promote its technologies available for commercialization.
APG HRT12	Provide public and industry access to the TechTracS database, which features approximately 18,000 updated and evolving new technologies, as well as technical briefs, diagrams, and illustrations.
APG 4TS4	Space transportation technical exhibits will be sponsored for at least five events reaching over 50,000 participants to improve public appreciation of the ongoing activities and benefits of NASA's space transportation research and technology development efforts.

Goal 9 **Extend the duration and boundaries of human space flight to create new opportunities for exploration and discovery.**

Objective 9.2 **Develop new human support systems and solutions to low gravity technological challenges to allow the next generation of explorers to go beyond low earth orbit.**

<i>Outcome 9.2.1</i>	<i>Identify & test technologies by 2010 to reduce total mass requirements by a factor of three for Life Support using current ISS mass requirement baseline.</i>
APG 4HRT14	Demonstrate ground test of a Mobile Intelligent Vehicle Health Management (IVHM) system for internal spacecraft operations that will provide environmental sensing capabilities and knowledge management services. The Mobile IVHM will perform independent calibration checks for environmental sensors; autonomously replace or substitute for failed environmental sensors; hunt down and isolate gas leaks and temperature problems; and provide a range of crew personal data assistant functions.

Objective 9.4 **Develop technologies to enable safe, affordable, effective and sustainable human-robotic exploration and discovery beyond low Earth orbit (LEO).**

<i>Outcome 9.4.1</i>	<i>Identify, develop and validate human-robotic capabilities by 2015 required to support human-robotic lunar missions.</i>
APG 4HRT1	Formulate guidelines for a top-down strategy-to-task (STT) technology R&D planning process that will facilitate the development of human-robotic exploration systems requirement.
APG 4HRT2	Charter an Operational Advisory Group of technologists and operators to prepare for two systems-focused Quality Function Deployment (QFD) exercises that will take place in FY 2005.
APG 4HRT3	Charter a Technology Transition Team that will review candidate human-robotic exploration systems technologies, and provide detailed updates to human-robotic technology roadmaps.

Objective 9.4 **Develop technologies to enable safe, affordable, effective and sustainable human-robotic exploration and discovery beyond low Earth orbit (LEO).**

<i>Outcome 9.4.1</i>	<i>Identify, develop and validate human-robotic capabilities by 2015 required to support human-robotic lunar missions.</i>
APG 5HRT1	Establish an integrated, top-down strategy-to-task technology R&D planning process to facilitate the development of human-robotic

	exploration systems requirements.
APG 5HRT2	Execute two systems-focused Quality Function Deployment exercises through an Operational Advisory Group (including both technologists and operators) to better define systems attributes necessary to accomplish human-robotic exploration operational objectives.
APG 5HRT3	Execute selected R&D-focused Quality Function Deployment exercises through an external/internal Technology Transition Team to review candidate human-robotic exploration systems technologies, and provide detailed updates to human-robotic technology road maps.
APG 5HRT4	Test and validate preferred engineering modeling and simulation computational approaches through which viable candidate architectures, systems designs and technologies may be identified and characterized. Select one or more approaches for ongoing use in systems/technology road mapping and planning.
Objective 9.4	Develop technologies to enable safe, affordable, effective and sustainable human-robotic exploration and discovery beyond low Earth orbit (LEO).
<i>Outcome 9.4.2</i>	<i>Identify and execute a research and development program to develop technologies by 2015 critical to support human-robotic lunar missions.</i>
APG 4HRT4	Conduct an "Industry Day" by mid-FY 2004 to communicate the Exploration Systems Enterprise vision and processes.
APG 5HRT5	Identify and analyze viable candidates and identify the preferred approach to sustained, integrated human-robotic solar system exploration involving lunar/planetary surfaces and small bodies, and supporting operations. Validate a focused technology R&D portfolio that addresses the needs of these approaches and identifies existing gaps in technological capabilities.
APG 5HRT6	Establish and obtain approval for detailed R&D requirements, roadmaps and program planning in key focused technology development areas, including self-sufficient space systems; space utilities and power; habitation and bioastronautics; space assembly, maintenance and servicing; space transportation; robotic networks; and information technology and communications.
Objective 9.4	Develop technologies to enable safe, affordable, effective and sustainable human-robotic exploration and discovery beyond low Earth orbit (LEO).
<i>Outcome 9.4.3</i>	<i>By 2016, develop and demonstrate in space nuclear fission-based power and propulsion systems that can be integrated into future human and robotic exploration missions.</i>
APG 4HRT5	Review nuclear propulsion and vehicle systems technology roadmap for alignment with exploration priorities, particularly human-related system and safety requirements.
APG 5HRT7	Develop Level 1/ Level 2 requirements for nuclear power and propulsion systems in support of selected human and robotic exploration architectures and mission concepts.
APG 5HRT8	Complete a validated road map for nuclear power and propulsion R&D, and related vehicle systems technology maturation.
APG 5HRT9	Formulate a demonstration mission plan for Jupiter Icy Moons

Orbiter that will test and validate nuclear power and propulsion systems for future human-robotic exploration missions.

Objective 9.4

Develop technologies to enable safe, affordable, effective and sustainable human-robotic exploration and discovery beyond low Earth orbit (LEO).

Outcome 9.4.4

Develop and deliver 1 new critical technology every 2 years in at least each of the following disciplines: in-space computing, space communications and networking, sensor technology, modular systems, and engineering risk analysis.

APG 5HRT15

Complete an Advanced Space Technology Program technology roadmap that interfaces appropriately with the technology planning of NASA's enterprises.

APG 5HRT16

Deliver at least one new critical technology in each key area (including: in-space computing, space communications and networking, sensor technology, modular systems, and engineering risk analysis) to NASA's enterprises, for possible test and demonstration.

APG 5HRT17

Prepare and announce the Centennial Challenge Cycle 2 major award purses, including competition rules, regulations, and judgment criteria.

Objective 9.5

Develop crew transportation systems to enable exploration beyond low Earth orbit (LEO).

Outcome 9.5.1

By 2014, develop and flight-demonstrate a human exploration vehicle that supports safe, affordable and effective transportation and life support for human crews traveling from the Earth to destinations beyond LEO.

APG 4TS1

The Demonstration of Autonomous Rendezvous Technology flight article will be certified for flight demonstration, establishing it as a test platform for demonstrating key technologies required to enable an autonomous (no pilot in the loop) approach to the International Space Station.

APG 4TS2

Conduct full reviews of OSP and NGLT programs, identifying acquisitions strategies, technologies, and lessons learned that are applicable to the new CEV program.

APG 5TS1

Conduct a detailed review of previous vehicle programs to capture lessons-learned and appropriate technology maturation; incorporate results into the human exploration vehicle requirements definition process.

APG 5TS2

Develop and obtain approval for human exploration vehicle Level 1 and Level 2 Requirements and the resulting Program Plan.

APG 5TS3

Complete preliminary conceptual design(s) for the human exploration vehicle, in conjunction with definition of an integrated exploration systems architecture.

APG 5TS4

Develop launch vehicle Level 1 Requirements for human-robotic exploration within an integrated architecture, and define corresponding programs to assure the timely availability of needed capabilities, including automated rendezvous, proximity operations and docking, modular structure assembly, in space refueling, and launch vehicle modifications and developments.

Objective 9.5	Develop crew transportation systems to enable exploration beyond low Earth orbit (LEO).
<i>Outcome 9.5.2</i>	<i>By 2010, identify and develop concepts and requirements that could support safe, affordable and effective transportation and life support for human crews traveling from the Earth to the vicinity or the surface of Mars.</i>
APG 4TS3	Compile a document that catalogs major architecture and engineering trade studies of space transportation architectures for human Mars exploration.
APG 5TS5	Conduct a preliminary conceptual design study for a human-robotic Mars exploration vehicle, in conjunction with definition of an integrated exploration systems architecture.

Goal 10 **Enable revolutionary capabilities through new technology.**

Objective 10.1	Improve the capability to assess and manage risk in the synthesis of complex engineering systems.
<i>Outcome 10.1.1</i>	<i>By 2005 demonstrate 2 prototype systems that prove the feasibility of resilient systems to mitigate risks in key NASA mission domains. Feasibility will be demonstrated by reconfigurability of avionics, sensors, and system performance parameters.</i>
APG 4HRT7	Develop a Prototype Concept Design Risk Workstation that provides the capability to identify, track, and trade-off risk in the conceptual design phase of missions. The workstation will integrate databases, visualization modules, solicitation routines, system simulations, and analysis programs that support an interactive system design process.
APG 5HRT10	Develop prototype design and organizational risk analysis tools to do risk identifications, assessments, mitigation strategies, and key trade-off capabilities not only between risks, but between risks and other mission design criteria.
APG 5HRT11	Develop a robust software tool for accident investigation that can help identify the causes of spacecraft, airplane, and/or other mission hardware accidents.

Objective 10.3	Leverage partnerships between NASA Enterprises, U.S. industrial firms, and the venture capital community for innovative technology development.
<i>Outcome 10.3.1</i>	<i>Promote and develop innovative technology partnerships between NASA, venture capital firms and U.S. industry for the benefit of all Enterprise mission needs, initiating three (3) partnerships per year.</i>
APG 4HRT8	Establish 3 partnerships with U.S. industry and the investment community using the Enterprise Engine concept.
APG 4HRT9	Develop 36 industry partnerships that will add value to NASA Enterprises.
APG 5HRT12	Establish three partnerships with U.S. industry and the investment community using the Enterprise Engine concept.
APG 5HRT13	Develop 12 industry partnerships, including the three established using the Enterprise Engine, that will add value to NASA Enterprises.
<i>Outcome 10.3.2</i>	<i>Facilitate on an annual basis the award of venture capital funds or Phase III contracts to no less than two SBIR firms to further develop or produce their technology through industry or government agencies.</i>

APG 4HRT10	Achieve through NASBO, the award of Phase III contracts or venture capital funds to 2 SBIR firms to further develop or produce their technology through industry or government agencies.
APG 5HRT14	Achieve through NASBO, the award of Phase III contracts or venture capital funds to no less than two SBIR firms to further develop or produce their technology through industry or government agencies.

Implementing Strategies to Conduct Well-Managed Programs

APG 4HRT13	Distribute at least 80% of allocated procurement funding to competitively awarded contracts, including continuing and new contract activities.
APG 5HRT15	Distribute at least 80% of allocated procurement funding to competitively awarded contracts, including continuing and new contract activities.
APG 4TS5	The Theme will distribute at least 80% of its allocated procurement funding to competitively awarded contracts.
APG 5TS6	Distribute at least 80% of allocated procurement funding to competitively awarded contracts, including continuing and new contract activities.

C.3 Office of Exploration Systems Role within NASA

The following section provides the official roles and responsibilities of the Office of Exploration Systems within NASA (per NPR 1000.3, Change 51, dated January 15, 2004; as provided on line as of 4 February 2004). Note that the official NPR is the online version.

C.3.1 Office Mission

This Headquarters Program Office is responsible for the Exploration Systems Enterprise, providing the executive leadership and programmatic direction for pioneering the identification, development, validation, and transfer of innovative, high-payoff exploration and related technologies and implement them in exploration projects. As such, the Enterprise Associate Administrator is responsible for the integration and prioritization of exploration Research and development investments, requiring a strong interface with the customers and users of the technology and development programs. The Exploration Systems enterprise shall provide the focus and direction to future exploration technologies by applying a strategy to task (to) technology analytical process involving an integrated team of users and developers. User-identified future operational needs shall define comprehensive requirements which will determine technologies and demonstrations (that) will be pursued and funded. The Exploration Systems Enterprise shall serve as the critical link among the requirements community, the technology community, and any eventual developmental and acquisition programs. The Exploration systems shall collaborate with the following customers: Office of Space Flight, Office of Biological and Physical Research, Office of Space science, Office of Earth Science, Office of Education, Space Architect, and Chief Scientist.

C.3.2 Responsibilities

The Associate Administrator for Exploration Systems is responsible for the following functions:

C.3.2.1 Leading the development of an Enterprise strategic implementation plan (including strategy, goals, and metrics) to guide the conduct of the Agency's exploration research and development.

C.3.2.2 Formulation, planning and advocating NASA's exploration research and developmental programs consistent with the Agency's Strategic Plan that includes negotiating Commitment Agreements with the Administrator, defining required policies and guidance, and approving program plans, and managing Level 1 requirements of development programs.

C.3.2.3 Leading the Enterprise budget development and approval process, managing corporate resource implementation responsibilities, and ensuring that program technical and financial performance goals are achieved.

C.3.2.4 Coordinating exploration research and development planning, policies, and programs with other Government agencies, industry, and academia, and conducting corporate communications and advocacy activities with technology partners, the educational community, the public, customers, and stakeholders.

Appendix D

Technology Challenges from Preliminary Requirements Studies

The following sections provide (1) information concerning “figures of merit” (FOMs) and (2) some technology challenges that have been identified through preliminary design reference mission studies by the Office of Exploration Systems (OExS) Requirements Division. Additional information, including formal requirements as well as updates to these challenges will be updated as future OExS Concept Exploration and Refinement (CE&R) Studies are initiated.

D.1 Figures of Merit

Figures of merit are used by the Office of Exploration Systems to ensure that strategic investments are properly aligned to implement the Vision of Space Exploration. The figures of merit are used to measure the benefit of one approach as compared to other alternatives within a decision model. Utilizing a standard, consistent set of measures makes it possible to compare alternatives in addition to providing insight into the performance sensitivities of the alternatives and variations due to different assumptions and inputs. Assessments of technology choices must be made within the context of specific mission concepts being considered. The following figures of merit are applicable to the Office of Exploration System requirements formulation and technology investment activities.

Safety and Mission Success: Measures of effectiveness associated with safety and mission success focus on determining the degree to which a mission concept or technology option ensures safety and reliability for all mission phases. To be sustainable, future space exploration systems and infrastructure, and missions pursued using them, must be reliable, and when astronauts are involved, they must be as safe as reasonably achievable. Emphasis is placed on understanding comparative values of safety related measures of performance discussed below:

Risks An assessment of the events that could result in loss of crew, loss of vehicle, and mission failure. These could include launch failure or failure during other mission events. The confidence levels of known and unknown aspects of the mission concept or technology choices should be addressed.

Includes assessments of the degree to which the mission concept or technology allows for simple interfaces within in or between elements. This also includes an assessment of the number and complexity of the associated interfaces. For example the number of elements, number of critical mission events, total mission duration, launch and return opportunities, etc.

Risk to public should be addressed for applicable mission phases. This should encompass risk during both the launch and reentry phase of crew

or cargo to the general populace, as well as planetary risk due to potential contamination (biological or nuclear).

- Hazards** An assessment of the mission and technology risks which have the potential to cause a mishap. This includes hardware, software, and operational issues that could result in loss of crew, personnel, vehicle, or mission.
- Aborts** An assessment of the ability of the mission concept or technology choice to provide for survival of the crew during various mission phases due to anomalies that result in early mission termination. Aborts could include early vehicle return or safe havens, but must result in safe return of the crew to Earth.
- Redundancy** An assessment of the design features which will allow for the safe crew return in the event of a system failure which otherwise would be catastrophic. Design redundancy should consider both redundancies within a system and between elements, as well as the ability of the system or technology to provide functional redundancy from dissimilar means.
- Reliability** An assessment of the probability that a mission concept or technology choice will successfully complete the desired mission, along with a confidence factor based on available data and model maturity.
- Contingencies** An evaluation of the technology or mission operations concepts that are not the primary methods of accomplishing a function, but used for mission success or crew safety. For example crew manual action required to overcome a docking system failure to allow de-mating of two elements.

Effectiveness: Measures of performance associated with effectiveness focus on determining the degree to which the mission concept, or technology option, effectively meet mission needs. Future space exploration systems and missions must be effective. In other words, the capabilities of a new system or infrastructure must be worth the costs of developing, building, and owning them. The goals and objectives achieved by the missions using those systems and infrastructures must be worth the costs and risks involved in operating them. Effectiveness must be determined case-by-case, based on the specific design objectives of the system or infrastructure, and based on the detailed mission objectives (e.g. science objectives) that may be achieved.

- Mission Objectives** Assessment of capability of the mission approach or technology choice to satisfy exploration objectives.
- Mass** Total mass required to be delivered to low-Earth orbit to support initial mission (includes pre-deployed infrastructure, if any) and the required mass for each subsequent mission. Also includes an assessment of the total number of launches required to emplace the necessary infrastructure as well as for each recurring mission.

Extensibility: Measures of effectiveness associated with extensibility focus on determining the degree to which the technology, subsystem, or system option effectively meet future mission needs.

Elements	Applicability of the elements, for example Crew Exploration Vehicle, lander, habitat, EVA suit, surface power, in meeting future mission needs.
Subsystems	Applicability of subsystems, for example life support system, in-space propulsion system, power, in meeting future mission needs.
Technologies	Applicability of specific technologies in meeting future mission needs.

Affordability: To be sustainable, future space exploration systems and infrastructures, and the missions pursued using them must be affordable. In other words, the costs for design, development, test and engineering for the systems must be consistent with projected future year NASA budgets. (The same is true for the recurring costs of additional copies of all exploration systems). Similarly, the costs associated with operating these systems in future space exploration missions must be consistent with projected future year NASA budgets. Assessments of affordability include the degree in which the proposed mission or technology option is expected to provide an affordable approach. Assessments in this focus area include both total expected costs as well as affordability assessments regarding expected funding profiles and phasing.

Development	Total cost for the design, development, test and evaluation of the required systems and facilities that constitute the element or mission concept under consideration.
Recurring	Total annual program, infrastructure, and facility costs necessary for execution of the mission concept (e.g. sustaining engineering, hardware production, ground and mission operations, etc.), assuming one mission per year.
Marginal	Additional cost necessary to execute one additional flight for the subject element or mission concept under consideration (e.g. hardware production, ground and mission operations, etc.).
Technology	Total costs required to advance the technology to a TRL level of 6.
Availability	An assessment of effort and associated risk required to bring the required technologies to TRL 6 by six years prior to initial operational capability date (9 years for technology that affects the overall system of systems). Includes assessments of the effort and associated risk to develop required elements and supporting infrastructure within the required schedule.

D.2 Technology Challenges

Human exploration beyond low-Earth orbit is an endeavor that will confirm the potential for humans to leave our home planet and make our way outward into the cosmos. Though just a small step on a cosmic scale, it will be a significant one for humans, because it will require leaving Earth on long missions with limited return capabilities. For example, the decision to go to Mars is a commitment to several months away from Earth, during which there are very limited return opportunities.

NASA is currently defining strategic mission concepts and key performance requirements for human exploration that radically reduce the cost and risk of such missions using advanced technologies and innovative systems strategies. These operations concepts are directed toward developing common capabilities and core technologies to be used for progressive missions beyond low-Earth orbit. This white paper identifies key exploration technology challenges in the areas of human support, in-space transportation, power, and miscellaneous cross-cutting technologies. The focus of the following discussion centers on the technology needs in support of human missions that may occur after the 2020 timeframe. In such, these challenges focus on robust exploration capabilities of the Moon as well as advanced technologies needed for the initial human exploration of Mars.

HUMAN SUPPORT

Protective measures must be devised to ensure crew health and maximize mission success as humans extend their reach beyond low-Earth orbit into the more hazardous environment of deep space for lengthy periods. Initial missions to the lunar surface will be weeks in duration, eventually extending to perhaps months. On the other hand, missions to Mars will much longer, ranging from eighteen to thirty months in duration. Advances in various human support technologies including radiation protection, zero-g countermeasures, remote medical care, advanced life support systems, and human-systems design are necessary to support humans as they explore beyond low-Earth orbit.

Radiation Protection: As the crew ventures beyond the protective environment of Earth, they are exposed to both Galactic Cosmic Radiation (remnants from the formation of the universe) and Solar Particle Events (solar flares from the Sun). Effective mathematical modeling of spacecraft systems including low-mass radiation protection of the crew and electronic systems are critical for future exploration endeavors. In addition, capabilities to enable early prediction of solar particle events or other helio-meteorological phenomena are vital.

Medical Care: Providing medical care to in-space crews has been a major concern since the beginning of human spaceflight. Great care is exercised when selecting crew to choose those not susceptible to contracting an illness while on a mission. It will be necessary to provide advanced medical diagnostic equipment both to the crew in-situ and the corresponding data to the medical teams back on Earth. Improvements to Earth-based medical system to make them lightweight and adapting them to space will require advancements.

Life Support System Closure: Developing technologies, which can significantly reduce the consumables required to support the crew during long-durations as well as minimizing system maintenance required by the crew is critical for human exploration. Life support technology focus areas include air and water loop closure, environmental monitoring, solid waste processing, thermal control, food packaging and eventually food production. Advanced sensor technologies to monitor and intelligent systems to control the environmental "health" of the advanced life support system, including air and water, are also needed. The degree of closure of life support systems is driven by technology,

crew size and mission durations, as well as periods of time when the vehicles are unoccupied. Specific focus areas of life-support system technology development include areas such as life support systems which are also integrated with power and propulsion system approaches, regenerable CO₂ removal and humidity control systems, oxygen generation technologies, CO₂ reduction, trace contaminant control systems, water closure systems including microbial control, and solid waste management.

Human-System Design: As extended-duration space-borne operations become increasingly self-sufficient, human performance emerges as a critical risk and design consideration. Improved methods of human-automation interaction, advanced information displays, supervisory control, intelligent decision support systems and on-board training approaches are necessary to reduce cost and risk while maintaining key performance capabilities.

IN-SPACE TRANSPORTATION

Advances in propulsion technologies that provide efficient delivery of crew and cargo, to and from exploration destinations, in order to reduce both total mission mass and crew exposure to the deep-space environment, are necessary. Given the total mass involved in many exploration architectures, this area is of prime importance and thus has been the focus of many studies and technology development efforts. Historically, propulsion technologies include high and low thrust propulsion systems involving chemical, nuclear, solar, and aeroassist forms of energy exchange.

Advanced Chemical Propulsion: Chemical propulsion systems which provide simple, safe, highly efficient, and cost effective main propulsion and reaction control system are needed for both far and near-term applications for exploration of lunar vicinity and Mars. Highly efficient, restartable, throttleable cryogenic main engines, which provide evolution potential to utilize locally produced propellants are needed for trans-lunar injection stages, landers, and ascent vehicles. Emphasis is placed on integrated main propulsion and reaction control system concepts utilizing non-toxic propellant. Leading propellant options include liquid hydrogen, liquid oxygen, methane, and ethanol.

Electric Propulsion Key Challenges: Evolutionary electric propulsion concepts for crew and cargo delivery are good candidates for future exploration missions. Concepts include solar electric propulsion for near-Earth cargo missions (100-1000's kWe total power) and nuclear power for both cargo and crew (1-10 MWe total power) for Mars applications. Electric propulsion concepts that enable long-life multi-use (2-4 year power life), highly efficient thrusters (3000-7000 second specific impulse), and overall efficient propulsion system specific performance (1-10 kg/kWe) are needed.

Nuclear Thermal Propulsion Key Challenges: Advanced nuclear thermal propulsion (860-980 seconds specific impulse, 2600+ K reactor operating temperature), with high thrust to weight ratios (3 to 1), with efficient hydrogen tank storage concepts (18% hydrogen tank fractions) may provide efficient transportation of cargo and crew to and from Mars.

Cryogenic Fluid Management: Providing the capability to manage large quantities of cryogenic fluids for long-periods is necessary for future human exploration missions. Cryogenic fluid management systems must be synergistic with propulsion, power, and life support system needs as well as being capable of evolving to incorporate

in-situ resources. Technologies enabling zero-g fluid transfer, mass gauging, acquisition, and pressure control, and zero-boil-off of cryogenic fluids including hydrogen, oxygen, methane are needed. Cryogen storage systems will also require efficient cryocoolers and advanced thermal insulation to achieve zero boil-off.

Aeroassist: Providing the capability for entry, descent, and soft landing of large systems is necessary for future human exploration of the Martian surface. Advances in thermal protection, deceleration systems such as high-Mach parachutes, as well as precision landing and hazard avoidance are necessary for future exploration missions. Aerocapture and aerobraking systems can reduce propellant requirements for orbit insertion.

Automated Rendezvous and Docking: Providing the capability to perform rendezvous and docking of multiple elements in remote locations with limited or no support of either ground or flight crews is necessary for many future exploration mission concepts. Key challenges include advanced sensor technologies, low impact docking systems, and automated operational concepts and computing algorithms.

POWER

Technology advances for power systems are focused on efficiently providing continuous high power at low cost across all phases of human exploration missions. These areas include in-space and stationary surface power generation, mobile power for rovers, energy storage, and power distribution systems. To enable robust exploration in near-Earth space and beyond, advances in each phase will be required.

Power Generation: Key technology challenges in power generation, distribution, and control range from crew system support (10's kWe) to high power generation for more advanced operational concepts such as in-situ resource utilization (10's kWe – 100's kWe) and electric propulsion (100's kWe to 1000's kWe). Power generation must accommodate both in-space and planetary surface environments for long-periods (1-7 years). Affordable, low risk systems that minimize crew maintenance requirements must be pursued. Key technology options for surface and transportation power generation include solar and nuclear concepts for both near-earth and Mars transportation applications.

Mobile Power: Mobile power for roving vehicles enables scientific expeditions stretching beyond the limits of a stationary surface habitat. To achieve this goal, rovers require high energy storage and/or high power generation capacity (10's kW-h) while maintaining volumetric compactness. Advanced batteries, fuel cells, and radioisotope power systems should be considered.

Energy Storage: Advanced energy storage systems are enabling technologies for non-continuous power generation systems and can provide emergency power during system failures. Such systems viable for human exploration must feature low cost and mass per unit energy stored while remaining reliable and operationally simple. Several storage options in this area include chemical energy with advanced batteries (affordable, high specific energy, long wet life and good charge retention), regenerative fuel cells (efficient, maintenance free, affordable concepts which are synergistic with common vehicle consumable storage needs), or solar dynamic systems.

Power Distribution: The needs for human exploration also include efficient high power distribution technologies for surface transmission and electric propulsion systems. High voltage power transmission can reduce the total mass for high power systems through increased efficiency, although it requires additional crew safety measures over similar low voltage operation. Other power distribution challenges include providing intelligent, self-diagnosing and correcting power management and distribution systems.

Miscellaneous and crosscutting Technologies

A number of cross-cutting technologies, including sensor miniaturization, in-situ resource utilization, advanced materials, thermal management, advanced habitation, advanced EVA, robotics, on-board computing, and simulation based design may offer important ancillary benefits such as crew risk reduction and enhanced science return to mission architecture.

Sensors and Instruments: As human expeditions venture beyond low-Earth orbit, more durable and reliable instrumentation will be needed. This includes a general category from computers and communications to bio-medical sensors. State-of-the-art components are rapidly improving in reliability and speed on the ground, however this push needs to be directed to space-based applications. Current electronics still require large packaging volumes and high cooling requirement that is levied upon other spacecraft systems, thus adding further complexity. Micro- and nano-size sensor technologies are viable options for reducing the size and mass of electronics, making them attractive to the designer.

In-Situ Resource Utilization: Technologies for “living off the land” are needed to support a long-term strategy for human exploration. Rather than transporting consumables such as oxygen, water, and ascent propellant from Earth, a planet’s atmosphere and other natural resources can be transformed into products needed for human exploration. The resources generated on-site can supplement existing consumables to reduce mission risk, or replace them for significant mass savings. While additional assets are required to process the raw materials, resulting products can be shared between separate functions, such as generating pure oxygen for both propellant and breathable air. Key ISRU challenges include resource identification and characterization, excavation and extraction processes, consumable maintenance and usage capabilities, as well as advanced concepts for manufacturing other products from local resources.

Advanced Materials: Exploration systems will require high strength-to-weight materials to reduce launch mass, space-durable materials to extend operational lifetime in extreme environments, and radiation tolerance for crew and spacecraft systems.

Thermal Management: Thermal management technologies are needed for dissipating waste heat from power, propulsion, life support, and ISRU systems, and for maintaining cryogenic fluids in long-term storage. Thermal management technologies include lightweight deployable radiators, high conductivity heat pipes for transporting heat over long distances, heat pumps for rejecting heat in hot environments, efficient cryocoolers, and thermal insulation.____Providing lightweight thermal heat rejection capability for the lunar and Mars surfaces conducive to surface environments such as

dust and temperature extremes is needed. Minimize sensitivity to leveling of radiators and maximize emissivity while minimizing mass. Methods to control and remove dust collected on radiator surface must be developed.

Advanced Habitation: Structural and materials advancements to provide large habitable volumes while minimizing mass, both in transit to and from planetary destinations as well as during surface explorations, are desired for human exploration missions. Key challenges include habitat concepts and emplacement methods, advanced lightweight structures, and developing integrated radiation protection for crew health and safety.

Advanced EVA: Technologies that enable routine surface exploration are critical to exploration activities. This includes advanced extra-vehicular activity suits and short and long-range rovers for surface exploration. Systems that provide routine and continuous surface exploration are keys to maximizing mission return. Key challenges include reducing carry weight of extra-vehicular mobility units and portable life support systems, improving overall suit mobility and dexterity, improving EVA system maintainability, dust mitigation approaches, and enhanced radiation protection. Key technologies include: advanced materials research which provide enhanced mobility and dexterity while maximizing radiation and puncture protection; low-weight, fast recharge batteries; low-weight efficient thermal control; advanced life support, and advanced sensors for environmental monitoring.

Robotic Human Support: Technologies are needed to augment humans where either safety or mission efficiency are concerned. Robotic systems are necessary for safety in areas such as EVA crew support, access to hazardous environments (e.g. high radiation), for increased mission efficiency in areas such as minimizing EVA hours for routine tasks (e.g. external inspection), extra-shift operations controlled from Earth, and crew amplification (e.g. one crew controlling a team of robots).

On-board Computing: Advances in low-power, low-mass, radiation tolerant, high-performance computing will enable a degree of self-sufficiency and autonomy that can fundamentally change mission capabilities and increase local efficiency while reducing risks associated with distant interplanetary exploration.

Simulation-based Design and Analysis: Novel design and analysis approaches are needed to improve system modeling and simulation, operations assessments, and enable accurate risk and cost estimation for life-cycle of proposed systems. Design models and engineering practices should be able to evaluate cost, performance and risk trades in the conceptual design phase. Life-cycle models can be used to diagnose design and operational faults during missions supporting efficient operations throughout the life of a system.

Communications: Providing the capability to provide continuous or near-continuous communications coverage, especially during critical mission events, is needed for future human exploration endeavors. Broadband communications (10-100's Mb/sec) aggregate coverage of telemetry, voice, and command as well as enhanced navigation for precision activities such as landing and automated rendezvous and docking serve as key communications challenges.

Supportability: Required levels of operational availability of spacecraft systems engaged in long-duration human exploration missions will be achieved in combination of high reliability, adequate redundancy, and maintenance. Since the astronaut crews will operate for extended periods of time at great distances from Earth, they must be provided with the means of accomplishing all possible maintenance tasks autonomously without direct intervention from ground personnel. This means that they must have available all of the tools, facilities, and materials necessary for maintenance actions. They must also have the capability to unambiguously identify the specific source and location of system failures and have all information required to allow them to perform the necessary maintenance actions.

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Appendix E

H&RT Program Content Guidelines

Details of the content of the several Human and Robotic Technology programs encompassed by this Program Formulation Plan will, of course, be developed during the coming months. As cited in Appendix D, a range of options, ‘figures of merit’ and notional technology challenges have been defined based on preliminary studies. These studies will continue and become more focused as a result of planned “Concept Exploration and Refinement” (CE&R) studies (to be started in Fall 2004).

As a working approach, the following are the guidelines concerning the appropriate technical content and scope for each of the several H&RT major and element programs.²⁵

E.1 Strategic Technical Challenges

It is key to the success of the Exploration Vision that our efforts in space exploration be ‘sustainable’ in diverse dimensions, including technical, economic and political aspects. In order to achieve ‘sustainability’ from a technical standpoint, future ambitious human and robotic space exploration must address the following overarching challenges:

- Reliability/Safety. How may future systems, architectures and missions achieve levels of reliability (and, where appropriate, safety) significantly greater than those possible today?
- Affordability. How may future systems, architectures and missions reduce life cycle cost (LCC) significantly below those that would be entailed in developing a systems using current technologies and existing concepts?
- Effectiveness. How may future human and robotic exploration missions and operations realize a dramatic improvement in effectiveness, effectiveness per unit reliability/safety and effectiveness per unit cost?
- Flexibility. How may future human and robotic exploration programs, missions and operations be highly ‘agile’ (able to change in a timely, cost-effective manner) in the context of future events, discoveries and innovations?

In this context, a family of ‘strategic technical challenges’ (STCs) has been defined that allow a working assessment of the potential value of various technology

²⁵ Additional information may be found in the March 16, 2004, Office of Exploration Systems POP Guidelines; provided in Appendix D.

investment options in realizing the overarching challenges listed above. These STCs include:

- Margins and redundancy in diverse subsystems, systems and systems-of-systems—but particularly those that must execute mission critical operations (such as transportation or life support) with the prospect of significant improvements in robustness in operations, reliability and safety.
- Reusability — using vehicles and systems during multiple phases of a single mission, and/or over multiple missions instead of ‘throwing away’ crew transportation, service modules, propulsion stages, and/or excursion systems after only a single mission.
- Modularity — employing common, redundant components, subsystems and/or systems that can improve reliability and support multiple vehicles, applications and/or destinations—with the potential for significant reductions in cost per kilogram.
- Autonomy — making vehicles and other systems more intelligent to enable less ground support and infrastructure, including the goal of accelerating application of ‘COTS’ and COTS-like computing and electronics in space.
- “ASARA” Human Presence in Deep Space – making it possible for humans to operate affordably and effectively in deep space and on lunar/planetary/other surfaces for sustainable periods of operations—while assuring that they are ‘as safe as reasonably achievable’.
- In-Space Assembly – docking vehicles and systems together on orbit instead of launching pre-integrated exploration missions from Earth using very heavy launch vehicles, and including in space maintenance, servicing, reconfiguration, evolution, etc., for exceptionally long-duration deep space operations.
- Reconfigurability – deploying systems that can be reconfigured following initial deployment, to enable adaptation to new circumstances, evolution at the systems-of-systems level as new elements are added, or to support high level system options.
- Robotic Networks – enabling ‘networks’ of cooperating robotic systems to be deployed that can work cooperatively to prepare landing sites, habitation, and/or resources and to extend the reach of human explorers.
- Affordable Logistics Pre-positioning – sending spares, equipment, propellants and/or other consumables ahead of planned exploration missions to enable more flexible and efficient mission architectures.
- Energy-Rich Systems and Missions – including both cost-effective generation of substantial power, as well as the storage, management and transfer of energy and fuels to enable the wide range of other systems-of-systems level challenges identified here).

- Space Resource Utilization – manufacturing propellants, other consumables and/or spare parts at the destination, rather than transporting all of these from Earth.
- Data-rich virtual presence – locally & remotely, for both real-time & asynchronous virtual presence to enable effective science and robust operations (including tele-presence and tele-supervision; tele-science; etc.).
- Access to Surface Targets that is precise, reliable, repeatable and global for small bodies, the Moon, Mars and other destinations—including both access from orbit and access from other locations on a planetary surface through the use of advanced mobility systems.

E.2 Technology Readiness Level Objectives

E.1.1 Advanced Space Technology Program (ASTP)

ASTP will focus on technology development and experimental and/or analytical proof-of-concept validation, consistent with TRLs 2 through 5, with particular emphasis on the transition from TRL 3 to 5. Within the ASTP, the Advanced Studies, Concepts and Tools (ASCT) element program will provide a dynamic, more often refreshed investment in technology research in the TRL 2-3 range.

E.1.2 Technology Maturation Program (TMP)

TMP will address on technology maturation and demonstration, consistent with TRLs 4 through 6, with particular emphasis on the transition from TRL 4 to 6. If justified, TMP may consider projects consistent with TRL 7 (systems-level technology validation in the flight environment). Within the TMP, the In-Space Technology Experiments Program (InSTEP) will provide opportunities for technology experiments and demonstrations to be conducted in the space environment, when appropriate.

E.1.3 Innovative Technology Transfer Partnerships (ITTP)

ITTP will address a range of TRLs, depending on the circumstances of the individual program (SBIR, STTR or Technology Transfer Partnerships), and the specific project proposed. However, in general it is expected that the emphasis of the STTR Program will be on emerging technologies at the TRL 2-3 level, and that emphasis of the SBIR Program will be on developing new technologies at the TRL 3-4.

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Appendix F

H&RT Program and Project Planning Templates

The following appendix provides a guide for H&RT element program and supporting project planning. The several H&RT programs encompassed by the Formulation Plan will be developed so as to be compliant with NPR 7120.5B, “NASA Program and Project Management Processes and Requirements” (or with successor versions of this document as they are approved).²⁶ However, ‘tailoring’ is planned to better address the unique objectives of the H&RT programs and the Office of Exploration Systems.

By the end of May 2004, a preliminary version of the Element Program Plan will be created. This version will include “TBDs”. By July 2004, the initial Element Program Plan will be updated to reflect decisions concerning intramural projects. Then, by the September/October 2004 timeframe, the Element Program Plan will be finalized for the year—including results from extramural project selection.

The paragraphs that follow provide a preliminary table of contents that will serve as the starting point for all H&RT Element Program Plans. Adjustments to this template should be limited to additions of subsections wherever necessary, or (if required) to the addition of a new section (with the approval of the appropriate Program Director).

F.1 Element Program Plans²⁷ (April 27 Version)

The H&RT Element Program Plans shall include the following contents:

- 1.0 Executive Summary
- 2.0 Background and Context
- 3.0 <Element Program> Program Goals and Objectives
- 4.0 Technology Needs and Opportunities
- 5.0 Program Scope
- 6.0 Technology Metrics Management
- 7.0 Resources
- 8.0 Program Authority and Management Structure
- 9.0 Program Oversight and Control

²⁶ Please note: these initial templates may be updated following initial review of emerging program plans in order to assure that key data will be provided in a consistent manner across the full scope of the H&RT programs.

²⁷ For additional details, see NPG 7120.5B; particularly page 112.

- 10.0 Risk Management
- 11.0 Program Integration and Administration
- 12.0 Tailoring
- 13.0 Change Log
- Appendices

Adjustments to this template should be limited to additions of subsections wherever necessary, or (if required) to the addition of a new section (with the approval of the appropriate Program Director).

1.0 Executive Summary

Overview of the Section

This section will provide an executive summary of the Element Program Plan. The content of this section must summarize how the specific Element Program fits into the Office of Exploration Systems, the overall H&RT Theme, as well as the element program's relationship to current and future programs & projects. Types of information to be summarized could include: Program Goals and Objectives; Work Breakdown Structure; Schedule and Major Milestones; and Program Deliverables.

Responsibility for Preparation of the Section (in order of responsibility)

- Element Program Manager, Element Program Team, Responsible Program Director, H&RT

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.

2.0 Background and Context

Overview of the Section

This section provides the overall programmatic and technical background and context for the specific program.

SECTION OUTLINE

- 2.1 Section Overview
- 2.2 National Context (Exploration Vision, other National Policy, Legislation, Regulations, etc.)
- 2.3 NASA Context (NASA Strategic Plan, Integrated Budget and Program Documents (IBPD), Annual Performance Goals (APGs), etc.)
- 2.4 Office of Exploration Systems Context (Charter, Organization, Programs)

2.5 Human and Robotic Technology Theme Context (Theme Overview, Programs Summary; H&RT Programs Work Breakdown Structure)

Responsibility for Preparation of the Section (in order of responsibility)

- H&RT, Responsible Program Director, Element Program Manager, Element Program Team

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.

3.0 <Element Program> Goals and Objectives

Overview of the Section

This section provides the goals and objectives for the program. These need to define both the purposes of the program and establish a 'work boundary' around the activity. They need to be defined in terms of work measures, success criteria, and final outcomes that meet the Office of Exploration System mission strategies and program expectations. (Focus is on the element program Goals and Objectives relative to the Goals and Objectives of H&RT, OExS, the Agency, and the President's Exploration Vision.)

SECTION OUTLINE

- 3.1 Section Overview
- 3.2 <Element Program> Goals and Objectives
- 3.3 <Element Program> Programmatic Requirements and Constraints
- 3.4 Relationships to Other Programs and Agreements

Responsibility for Preparation of the Section (in order of responsibility)

- Responsible Program Director, Element Program Manager, Element Program Team, H&RT

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.
- The first draft of this section will be provided by the Responsible Program Director.

4.0 Technology Needs and Opportunities

Overview of the Section

This section provides an overview of the ‘customers and stakeholders’ for this element program; it includes various sources and types of space technology needs that will guide the formulation and planning for the element program.

SECTION OUTLINE

- 4.1 Section Overview
- 4.2 Customer and Stakeholder Definition and Advocacy
- 4.3 Office of Exploration Systems Technology Needs and Opportunities
 - 4.3.1 The Exploration Vision “Road Map”
 - 4.3.2 The Spiral Development Process
 - 4.3.3 Human and Robotic Technology “Cycles of Innovation”
 - 4.3.4 H&RT Strategic Technical Challenges (STCs) and Systems-of-Systems Level Technology Opportunities
 - 4.3.5 Far-Term Needs: Human and Robotic Exploration Design Reference Architectures (DRAs) and Missions (DRMs) (including a summary of the trade space)
 - 4.3.6 Near-Term Needs: Project Constellation Technology Needs and Capability Gaps
- 4.4 Other Space Technology Needs and Opportunities
 - 4.4.1 Addressing the Challenges of Future Space Missions
 - 4.4.2 NASA Space Exploration Vision Challenges
 - 4.4.3 Other Space Mission Challenges
- 4.5 Summary of Technologies of Broad Potential Value to NASA and Other Future Space Activities

Responsibility for Preparation of the Section (in order of responsibility)

- H&RT, Responsible Program Director, Element Program Manager, Element Program Team

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.

5.0 Program Scope

Overview of the Section

This section will state clearly the scope of the element program. The section will establish the overall approach the program will take to meeting its programmatic and technical goals and objectives (within constraints), including the initial technical priorities for the investments to be made. The section will describe how the work will be performed.

SECTION OUTLINE

- 5.1 Section Overview

- 5.2 Technology Needs and Opportunities be addressed by <Element Program>
 - 5.2.1 Strategic Technical Challenges
 - 5.2.2 Capability Gaps
 - 5.2.3 Technologies of Broad Potential Value
- 5.3 <Element Program> Technical Themes
- 5.4 <Element Program> Research and Development Approach(es)
- 5.5 Project Formulation and Acquisition Strategy
- 5.6 Technology Assessment
 - 5.6.1 Current State of the Art: Technology Readiness Level
 - 5.6.2 Assessment of Research and Development Degree of Difficulty
 - 5.6.3 Other Relevant Programs / Investments
- 5.7 <Element Program> Research and Development Priorities
- 5.8 <Element Program> Work Breakdown Structure
- 5.9 <Element Program> Deliverables
- 5.10 <Element Program> Schedule and Major Milestones

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.

Responsibility for Preparation of the Section (in order of responsibility)

- Element Program Manager, Element Program Team, Responsible Program Director, H&RT Leadership (see working note above.)

6.0 Technology Metrics Management

Overview of the Section

This section documents the approach that will be followed in identifying and tracking key figures of merit (i.e., 'technology metrics') for the Element Program. TMM ('technology metrics management') provides the means to manage an R&D program within a larger spiral development-based program—with capabilities to facilitate industrial spin-offs, technology infusion into current and future programs & projects and a means to measure and assess success of work. TMM for the H&RT program will provide the capability to document, manage & control baselines, assess technology in terms of value to goals and objectives, and to provide tools for monitoring and assessing program and project performance.

SECTION OUTLINE

- 6.1 Section Overview
- 6.2 H&RT Technology Investment Portfolio Approach
 - 6.2.1 Integrated Technology Analysis Methodology (ITAM)
 - 6.2.2 Role of Technology/Systems Analysis

- 6.3 Determination of Technology Metrics
 - 6.3.1 TMM for Systems-of-Systems STCs
 - 6.3.2 TMM for Project Constellation Technology Gaps
 - 6.3.3 TMM for Other Space Technology needs
- 6.4 Technology Option Prioritization Process
 - 6.4.1 Process Overview
 - 6.4.2 Technology Assessment Approach
 - 6.4.3 Data Management for TMM
- 6.5 Focused <Element Program> Technology Portfolio & Metrics
 - 6.5.1 < Technical Theme 1>
 - 6.5.1.1 Problems to be Addressed
 - 6.5.1.2 R&D Objectives and Metrics: <Name of 1st Area>
 - 6.5.1.3 R&D Objectives and Metrics: <Name of 2nd Area>
 - 6.5.1.4 Etc.
 - 6.5.2 <Technical Theme 2>
 - 6.5.2.1 Problems to be Addressed
 - 6.5.2.2 R&D Objectives and Metrics: <Name of 1st Area>
 - 6.5.2.3 R&D Objectives and Metrics: <Name of 2nd Area>
 - 6.5.2.4 Etc.
 - 6.5.3 <Technology Theme 3>
 - 6.5.3.1 etc.
 - 6.5.4 etc.
- 6.6 <Element Program> Technology Assessment
 - 6.6.1 <Element Program> - Key Technology Metrics
 - 6.6.2 <Element Program> - Assessment of Key Technologies
 - 6.6.3 Other Relevant Technology Developments

Responsibility for Preparation of the Section (in order of responsibility)

- Element Program Manager, Element Program Team, Responsible Program Director, H&RT

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.

7.0 Resources

Overview of the Section

This section will present the resources required to execute the element program.

Working Notes and Additional Guidance for Teams:

- This section will be added after the April-May Program Formulation process.

Responsibility for Preparation of the Section (in order of responsibility)

- Responsible Program Director, H&RT Leadership, Element Program Manager, Element Program Team

8.0 Program Authority and Management Structure

Overview of the Section

This section provides the program management structure and documents authority within that structure. This section will provide an overall description (with templates referenced in the appendices) showing how the Element Program will function and interact internally and externally with other NASA/non-NASA organizations. A listing of participating NASA Center and personnel will be included in the appendix.

SECTION OUTLINE

- 8.1 Section Overview
- 8.2 Program Management Structure
- 8.3 Program Authority

Responsibility for Preparation of the Section (in order of responsibility)

- Responsible Program Director, Element Program Manager, H&RT

Working Notes and Additional Guidance for Teams:

- This section will be added following the April-May 2004 formulation process.

9.0 Program Oversight and Control

Overview of the Section

This section provides the plan for program oversight and control. Discussion will include program/project management reviews and their success criteria for movement to the next critical milestone or how the work will be terminated at each review point. The section will state how Earned Value Management techniques will be applied to the Element Program.

SECTION OUTLINE

- 9.1 Section Overview
- 9.2 <Element Program> Earned Value Management
- 9.3 Technical Progress Verification and Reporting
- 9.4 Program Resources Accounting and Reporting
 - 9.4.1 Financial Resources Planning / Performance
 - 9.4.2 Personnel Resources Planning / Performance
 - 9.4.3 Other Resources
- 9.5 Program Contracting Planning and Controls

- 9.6 Program Quarterly Status Reviews
- 9.7 Major Project Management Reviews
- 9.8 Termination Review Criteria

Responsibility for Preparation of the Section (in order of responsibility)

- H&RT, Responsible Program Director Element Program Manager

Working Notes and Additional Guidance for Teams:

- An initial version of this section should be included in the May 2004 Element Program Plan.

10.0 Quality and Risk Management

Overview of the Section

This section will document the quality and risk management goals, objectives, plans and processes of H&RT within this Element Program. Timely and effective management of risk is critical to the success of H&RT; in fact, an overall strategic purpose of the H&RT investment portfolio is to mitigate the risks for future systems developments involving new capabilities. Risk management provides the tools and capability to produce a programmatic or technical impact indicator of a measurable baseline. Maintaining and exceeding well-defined measures within the baseline and meeting or exceeding acceptable levels of established risk measures quality.

SECTION OUTLINE

- 10.1 Section Overview
- 10.2 Risk Management
 - 10.2.1 Goals and Objectives
 - 10.2.2 Risk Assessment Approach
 - 10.2.3 <Element Program> Technology Risk Mitigation Plan
 - 10.2.4 Ground and Space Environmental Impacts
- 10.3 Quality Assurance and Management
 - 10.3.1 Goals and Objectives
 - 10.3.2 <Element Program> Quality Management Approach
 - 10.3.3 Use of ISO Practices and Standards
 - 10.3.4 Verification and Validation Methodology and Test Planning
 - 10.3.5 Safety and Mission Success Considerations

Responsibility for Preparation of the Section (in order of responsibility)

- Responsible Program Director, Element Program Manager, Element Program Team, H&RT

Working Notes and Additional Guidance for Teams:

- A draft version of the section will not be completed until post-May 2004.

11.0 Program Integration and Administration

Overview of the Section

This section Management discusses the tools, processes, and the integrated program execution framework (including organization structure, contractor support, tool-related training, process & document control, etc.) to be used for the management of the program work activity.

SECTION OUTLINE

- 11.1 Section Overview
- 11.2 Program Configuration Management Plan
- 11.3 Data Management Processes and Systems
- 11.4 Program and Projects Lessons Learned
- 11.5 Program Logistics
- 11.6 Program and Project Documentation
- 11.7 Project Management Plan Requirements
- 11.8 Commercialization Opportunities

Responsibility for Preparation of the Section (in order of responsibility)

- Responsible Program Director, Element Program Manager, Element Program Team, H&RT.

Working Notes and Additional Guidance for Teams:

- A draft version of the section will not be completed until post-May 2004.

12.0 Tailoring

Overview of the Section

This section will document 'tailoring' that has been done in H&RT program management documentation, vis-à-vis the requirements of NPR 7120.5.

Responsibility for Preparation of the Section (in order of responsibility)

- Responsible Program Director, Element Program Manager, Element Program Team, H&RT

Working Notes and Additional Guidance for Teams:

- A draft version of the section will not be completed until post-May 2004.

13.0 Change Log

Overview of the Section

This section will the Change Log for the Element Program Plan.

Responsibility for Preparation of the Section (in order of responsibility)

- Element Program Manager, Responsible Program Director, Element Program Team, H&RT

Working Notes and Additional Guidance for Teams:

- A draft version of the section will not be completed until post-May 2004.

Appendices

(Standard Appendices to be included in every element program plan)

- A Glossary of Acronyms**
- B Selected Bibliography and References**
- C NASA Program Directives and Guidelines and Procedures**
- D Technology Needs and Requirements Details**
- E External Program Coordination**
- F Other Element Related Subjects**

This concludes the draft outline for Element Program Plans.

F.1.2 NPR 7120.5b Compliance

The following are the recommended sections for a program plan provided by NPR 7120.5b; these will be included in the required H&RT Element Program Plan (outline provided above), and/or the H&RT Major Program Plan (outline to be provided), including ASTP, TMP and ITTP:

1. Introduction
2. Program Objectives
3. Customer Definition And Advocacy
4. Program Authority And Management Structure
5. Program Requirements
6. Program Schedule
7. Program Resources
8. Controls
9. Relationships To Other Programs And Agreements
10. Acquisition Strategy
11. Technology Assessment
12. Commercialization Opportunities
13. Data Management
14. Safety And Mission Success
15. Risk Management
16. Environmental Impact

17. Logistics
18. Test And Verification
19. Reviews
20. Termination Review Criteria
21. Tailoring
22. Change Log

F.2 Project Plans²⁸

H&RT projects will include both extramural (non-NASA Principal Investigator (PI)) and intramural (NASA PI) efforts. This projects will be developed through to-be-established competitive processes; see Section 5 of this document. Once selected, the following shall be included in appropriate H&RT Project Plans, including projects within each of the Element Programs Plans within each of these three major programs:

1. Introduction
2. Objectives
3. Customer Definition And Advocacy
4. Project Authority
5. Management
6. Project Requirements
7. Technical Summary
8. Logistics
9. Schedules
10. Resources
11. Controls
12. Implementation Approach
13. Acquisition Summary
14. Program/Project Dependencies
15. Agreements
16. Safety And Mission Success
17. Risk Management
18. Environmental Impact
19. Test And Verification
20. Technology Assessment
21. Commercialization
22. Reviews
23. Termination Review Criteria
24. Tailoring
25. Change Log

²⁸ For additional details, see NPG 7120.5B; particularly page 117.

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Appendix G

H&RT Earned Value Management System(s)

The several H&RT program plans to be developed under the auspices of this Formulation Plan will provide the management context for the development and execution of Earned Value Management System(s) (EVMS) by each of the R&D projects within these programs.

As we move forward in program formulation, a coherent and integrated approach to EVMS for H&RT programs/projects will be selected and disseminated across the H&RT team.

The goal will be to require each program team (working with the individual projects) to track progress and to statistically forecast the final required funds for the program (and individual project) to complete each ‘innovation cycle’ in support of planned development spirals. Key characteristics of the EVMS approach for H&RT will include determination and forecasting of:

- Cost Performance Index (CPI), the ratio of the earned value (EV) to the total (actual) costs; and,
- Schedule Performance Index (SPI), the ratio of the EV to the planned value.

Each program team will be responsible for overseeing the implementation of one or more R&D projects, each of which are focused on resolving one or more key technical hurdles that impede the successful application of specific technologies (with well-defined technical characteristics; i.e., ‘metrics’) in future space systems. Individual projects, and in the parent programs, will be required to provide Quarterly Status Reports (QSR) to NASA Headquarters management.

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Appendix H²⁹

DARPA R&D MANAGEMENT MODEL

The corporate R&D organization for the Department of Defense, DARPA was created 46 years ago in the wake of the launching of Sputnik. DARPA manages and directs basic and applied research and development projects totaling \$3B per year and including activities where risk and payoff are both very high and where success may provide dramatic advances in military capabilities.

DARPA's culture encourages taking risks and tolerates failure, with most of its projects being aligned to a finite number of "strategic thrusts" (e.g., "Force Multipliers for Urban Area Operations"). DARPA pursues *transformational capabilities*³⁰ based upon focused R&D investments with the potential for high technical payoffs. To manage this work, DARPA maintains a small, flat, agile organization, with many of its technical staff being on assignment to DARPA for no more than three to five years, through either the traditional Intergovernmental Personnel Act (IPA) routes or through an Experimental Personnel Hiring Authority.

DARPA projects are intended to be results-oriented and differ from traditional R&D methods. In DARPA's view, the traditional approach, where lengthy proposals are written and submitted to an august group of peer reviewers, is time consuming and leads to an inefficient use of resources, with only a fraction of the research ever being combined to form useful products and/or processes (see Figure 1).

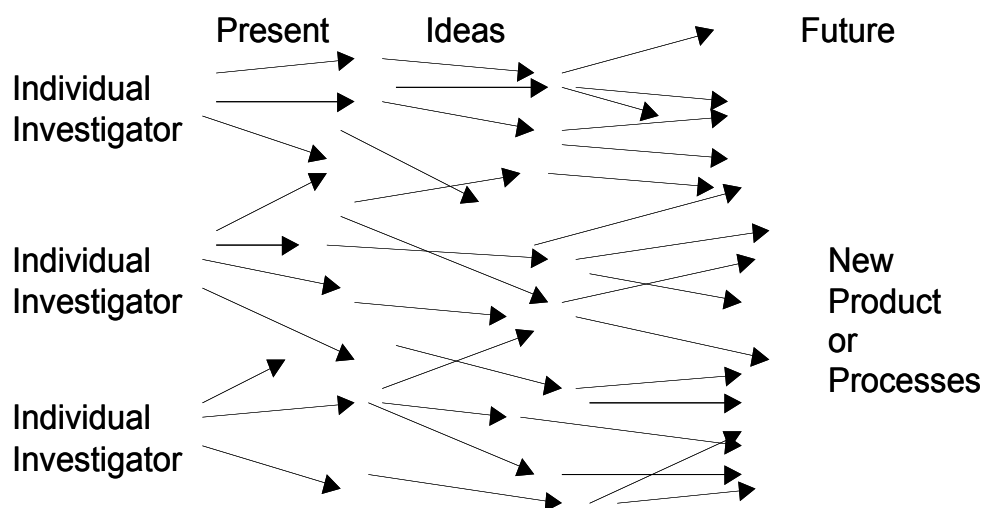


Figure 1. The traditional approach to technology development

²⁹ Prepared by R. Wegeng and N. Suzuki (from references cited).

³⁰ Other terms that have been used to describe the objectives of DARPA R&D include "radical innovation", "revolutionary technologies", and "disruptive capabilities". Disruptive capabilities are more than just new technologies; they are transformations in operations and strategy enabled by synergistic combinations of technologies.

DARPA's alternative to the traditional R&D method is termed the "end-game" approach, as indicated in Figure 2. By first defining the desired product or process and the anticipated technology needs, research teams can better coordinate their efforts and a high rate of return on technology development can be realized. The results of fundamental research are tied to the needs of the technologists, who then build on this information to further create new and useful knowledge. The DARPA program manager is said to play the role of the "technology midwife," who ensures that discoveries will move rapidly from the laboratory to valuable applications.

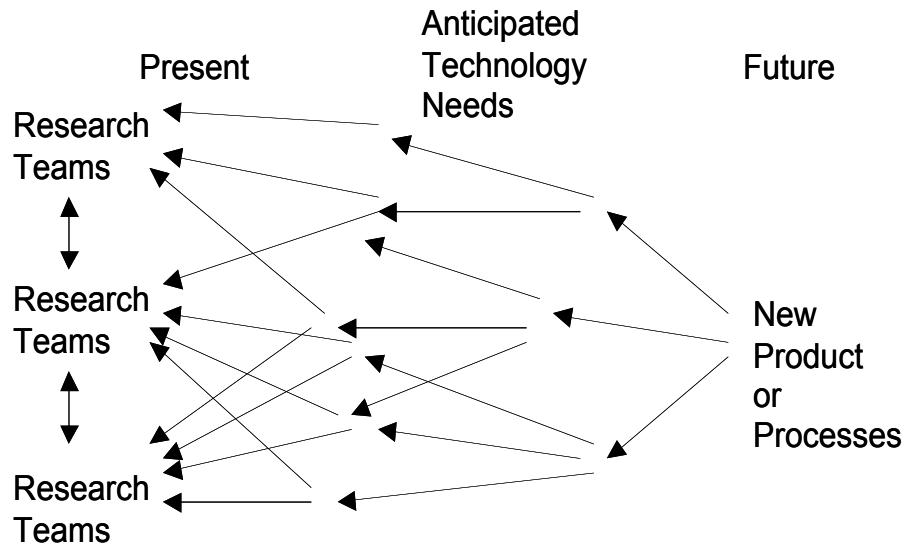


Figure 2. The "end-game" approach to technology development

The primary recipients of DARPA funds are typically researchers and research organizations in industry and universities, with smaller amounts going to US government and federally funded laboratories. Start-up firms frequently participate, especially if a technology has substantial commercial potential, as do microelectronics and computers, or when DARPA ideas could impact the long-term competitive position of existing firms' products. DARPA sometimes acts as a catalyst for innovation by seeding research communities in promising new technology areas, making iterative investments in the underlying technology base from development through proof-of-concept. Additionally, in some cases, DARPA funds large-scale demonstrations that integrate individual components. Performing a demonstration may require DARPA to act as a "system of systems" integrator, funding the engineering work required to meld different system functions into a new capability that is more than the sum of its parts.

DARPA program managers have also been described as "proactive techno-scouts", constantly searching for a way to engage advances in science and technology. In some ways, this can be compared to investment managers within venture capital organizations. For example, there are seven key questions that must be answered by DARPA program managers for each R&D investment, including one that deals with exit strategies:

- What are you trying to accomplish?
- How is it done today and what are the limitations?
- What is truly new in your approach that will remove current limitations and improve performance? By how much? A factor of 10? 100? More?
- If successful, what difference will it make and to whom?
- What are the midterm exams, final exams, or full-scale applications required to prove your hypothesis? When will they be done?
- What is the DARPA “exit strategy?” Who will take the technologies that you have developed and turn them into a new capability or a real product?
- How much will it cost?

Many of the most productive features of the DARPA model can be imported for useful purposes to the Office of Exploration Systems. For example, the Advanced Space Technology (AST) Program can be used to seed advances in science and low-TRL technology development. In addition, the Technology Maturation Program can “mine” the AST Program as well as R&D activities of others to incorporate new technologies, as part of a spiral transformation process, within either an ongoing spiral or within new spirals as appropriate.

More generally, elements of the DARPA approach that seem appropriate for consideration can be restated as follows:

- Invest in basic technologies that can lead to fundamental technical advantages.
- Build communities-of-change-state advocates.
- Define important, specific “strategic thrusts” in detail across multiple scenarios.
- Support the conceptual development of integrated, transformational capabilities.
- Test promising transformational capabilities in large-scale, proof-of-concept demonstrations.
- Work with agency leadership to build enterprise commitment to implement specific transformational capabilities.

Selected References

Dubois, LH, 2003. “DARPA’s Approach to Innovation and Its Reflection in Industry,” *Reducing the Time from Basic Research to Innovation in the Chemical Sciences: A Workshop Report to the Chemical Sciences Roundtable*, (2003), National Research Council.

Van Atta, RH, et.al., 2003. “Transformation and Transition: DARPA’s Role in Fostering an Emerging Revolution in Military Affairs,” *Institute for Defense Analyses*, (April 2003)

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Appendix I

HUMAN AND ROBOTIC TECHNOLOGY FORMULATION TEAM ROSTER

(12 June 2004)

As a part of the NASA response to the new National Vision for Space Exploration, and the creation of the new Human and Robotic Technology Theme (beginning in FY 2005), a major H&RT program formulation effort is being undertaken during FY 2004. This effort will involve participants from across diverse NASA Field Centers, under the leadership of program directors and program managers at NASA headquarters.

The following is a summary of the Program Formulation Team(s) for the Human and Robotic Technology (H&RT) Program Formulation Process. Included in this package are team members for the following formulation efforts:

- **Advanced Space Technology Program**
 - Advanced Studies, Concepts and Tools
 - Advanced Materials and Structural Concepts
 - Communications, Computing, Electronics and Imaging
 - Software, Intelligent Systems and Modeling
 - Power, Propulsion and Chemical Systems
- **Technology Maturation Program**
 - High Energy Space Systems
 - Advanced Space Platforms and Systems
 - Advanced Space Operations
 - Lunar and Planetary Surface Operations
 - In-Space Technology Experiments Program
- **Innovation Technology Transfer Partnerships Program**
 - Technology Transfer Program
 - Small Business Innovation Research (SBIR) Program
 - Small Business Technology Transfer (STTR) Program

The preliminary 'technical scope' of each of these major programs and element programs is provided in an other paper entitled: "Human and Robotic Technology Programs: Technical Themes."

PLEASE NOTE:

- This is a ‘living document’ – it will be updated as H&RT Program Formulation progresses. **CHANGES Suggested since 24 April 2004 will be considered for incorporation as part a Roster Update following the 29-30 April “kick-off” meeting.**
- This is a ‘controlling document’ – only the individuals formally identified in this document will be involved in the implementation of the planning process (although others may invited on an ad hoc basis to provide specific inputs to an official member).
- Also, this formulation planning ‘roster’ includes identification of “Enterprise Coordination *Ex Officio* Team Members”; these individuals should be invited to meetings and involved as full team members for purposes of discussion, outreach, coordination, etc. However, it is not expected that they will have a personal role in writing the plan(s).
- The members of the Exploration Systems Technology Coordination Group (a NASA-wide group for the coordination of the diverse NASA programs that are pursuing or have an interest in the Exploration Vision, and/or the development of exploration technologies/H&RT) are documented elsewhere.
- **The program formulation efforts to be undertaken by the teams identified in this roster are highly sensitive; please assure that during team teleconferences and meetings that ONLY official sanctioned team members are participating in the activities.**

ALL team members should be provided with a hard copy of this instruction, and verbally reminded.

Although the Element Program Plans will not be ‘solicitations’, nevertheless—as with any program plan—they will influence significantly future procurement activities; Again, please assure that during team teleconferences and meetings that ONLY official sanctioned team members are participating in any team activities.

1.0 Advanced Space Technology Program (ASTP)

The following are the members of the overall formulation team for the Advanced Space Technology Program. The critical roles to be performed by this team include: (a) developing an approach for how the various element programs within ASTP will interact with one another, with the ITTP and with the Technology Maturation Program; (b) serving as knowledgeable 'traffic cops' in reviewing the element program plans as they emerge, and (c) supporting the development of a draft ASTP Program Plan.

This initial set of names is based on the working inputs received as of 16-22 April 2004; updates and revisions are expected as additional selections are made and/or updates to initial center candidate lists are received.

1.0.1 Members of the ASTP Overall Formulation Team

NASA HQ Lead

- **Terry Allard, Ph.D. (OExS).**

NASA HQ Team Members (Element Program Managers)

- **Doug Craig (OExS).**
- **Christopher Moore, Ph.D. (OExS).**
- **Barbara Wilson, Ph.D. (Acting³¹).**
- **Butler Hine (OExS; on Detail from ARC).**

Center Team Members

- **Bill Van Dalsem Ph.D. (ARC).** Providing extensive program management experience, including serving as Deputy Program Manager for the former CICT program; technical background in modeling and simulation.
- **Dave Hoffman (GRC).** Providing needed expertise in the areas of power and propulsion related systems analysis, and R&D in power and propulsion. (Project Manager for the former MSM Energetics Project.) Also brings considerable international coordination and ISS project experience.
- **Lisa Wood Callahan (GSFC).** Providing needed expertise in the broad subject matter of the former Mission and Science Measurement Technology program and the transition to the new Human and Robotic Technology Theme. Also provides experience as leader for center IR&D programs.
- **Tim Krabach, Ph.D. (JPL).** Providing needed expertise in the areas of small spacecraft concepts, microdevices and nanotechnology, optics, photonics and other areas. Also brings experience in management of NASA R&D programs and in research laboratory management.

³¹ Dr. Wilson is a former JPL Chief Technologist, and former Director of the JPL Center for Space Microelectronics. (IPA paperwork in process.)

- **Al Conde (JSC).** Providing needed expertise in the areas of technology assessment, human exploration architectures, and flight experiment planning. Also brings experience in payload integration for both the Space Shuttle and the ISS programs. Also a member of the InSTEP planning team.
- **David E. Bartine (KSC).** Providing needed expertise in the areas of diverse areas of spaceport and range technology, with knowledge of advanced manufacturing, advanced power, materials and coatings and other areas. Also has experience with Nuclear systems technologies (including the SP-100 program)
- **Sharon Welch (LaRC).** Providing needed expertise in the areas of advanced technology program formulation, planning and advocacy; also brings experience in planning for novel approaches to space exploration, based on new technologies.
- **Dennis E. Griffin (MSFC).** Providing needed expertise in the areas of materials, processes and manufacturing; with an emphasis on establish technical standards for future materials and the related selection of flight hardware systems materials.

Team Members who will provide H&RT Cross-Pollination

- **Maria So (GSFC).** Providing needed expertise in the areas of in space mission systems engineering, technology development planning and management, and technology database management. Former manager of the NASA Technology Inventory system; currently Associate Branch Head working on space mission systems engineering. Cross pollinate from the Technology Maturation Program overall formulation team.

Enterprise Level Coordination

- **Gene Trinh (Code U).** Providing needed coordination of advanced space technology needs, planning and programs.
- **Parminder Ghuman (GSFC/Earth Science Technology Office (ESTO), representing Code Y).** Providing needed coordination between ESTO and advanced space technology needs, planning and programs.

The paragraphs that follow provide the names of are the members of the several element program formulation teams within the Advanced Space Technology Program.

I.1.1 Members of the ASTP Advanced Studies, Concepts and Tools (ASCT) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Douglas Craig (OExS).**

Center Team Members

- **Mark Shirley, Ph.D. (ARC).** Providing needed expertise in the areas of information technology and model-based reasoning; served as the chief technologist for the former ECS (engineering for complex systems) program. Also provides cross-pollination with Software, Intelligent System & Modeling.
- **Sharon Garrison (GSFC).** Providing needed expertise related to the NASA Institute for Advanced Concepts (NIAC); current COTR for the NIAC.
- **Jeffrey J. Rusick (GRC).** Providing needed expertise in the area of probabilistic, physics-based risk assessment and analytical tools. Also provides experience as a former project manager within the former ECS program.
- **Steve Wall (JPL).** Providing needed expertise in the areas of systems analysis, mission and systems design, mission operations and concurrent engineering. Brings experience as the leader of JPL's Center for Space Mission Architecture and design.
- **Deborah J. ("Deb") Neubek (JSC).** Providing needed expertise in the areas of advanced design and conceptual studies, including both specific studies as well as tool development (including analytical / integrated design environments). Also brings Space Station flight program experience.
- **Edgar Zapata (KSC).** Providing needed expertise in the areas of systems engineering, Space Shuttle ground operations, spaceport and range modeling and technology planning, advanced concepts studies, and analytical tools development.
- **Pat Troutman (LaRC).** Providing needed expertise in the areas of advanced concepts studies, novel mission concepts analysis and various technical disciplines. Brings experience related to oversight of NASA's former Revolutionary Aerospace Systems Concepts (RASC) program.
- **Daniel O'Neil (MSFC).** Providing needed expertise in the areas of online systems development, innovative concepts studies, integrated high-level technology-systems analysis tools. Brings experience as project lead for the "ATLAS" development effort.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Patrick George (GRC).** Providing needed expertise in the areas of ISS power systems, NASA-ESA collaboration and space solar power R&D. Also serves as an SBIR/STTR subtopic manager. Coordination with Technology Maturation Program.
- **Neville Marzwell, Ph.D. (JPL).** Providing needed expertise in the areas of advanced space systems concepts, modular systems, satellite servicing systems, robotics, advanced power systems, and other areas. Also brings experience in both industry and NASA (JPL) research activity planning and

management. Coordination with TMP Advanced Space Platforms and Systems Program.

Ex Officio Team Members who will provide Enterprise Coordination

The following individual(s) is/are named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Don Monell (OExS/RQ).** Providing needed expertise in systems engineering, with and emphasis in the areas of modeling and simulation (involving advanced transportation systems and other areas).
- **Faith Chandler (NASA HQ Office of Safety and Quality Assurance).** Providing coordination with Agency modeling and tools related to probabilistic risk assessment, problem/failure tracking and management, and related topics.

I.1.2 Members of the ASTP Advanced Materials & Structural Concepts (AMSC) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Christopher Moore, Ph.D. (OExS).**

Center Team Members

- **Bernie Laub (ARC).** Providing needed expertise in the areas of thermal protection systems materials.
- **Andy Eckel, Ph.D. (GRC).** Providing needed expertise in the areas of advanced metallic materials, non-metallic materials, and high temperature ceramic composites; experience with analysis of advanced materials (with emphasis on applications in propulsion).
- **Jennifer Dooley, Ph.D. (JPL).** Providing needed expertise in the areas of precision deployable structures, actuators, and cryogenic thermal control of distributed systems; also brings extensive experience in technology challenges and planning for large space telescope systems (including the Terrestrial Planet Finder (TPF) concept).
- **Eric Thaxton, Ph.D. (KSC).** Providing needed expertise in the areas of fracture mechanics, advanced structural concepts and analysis, cryogenic storage vessels, and others. Brings experience in support of Shuttle, ISS and other flight programs as well as development/management of ground technology test beds.
- **John Connell, Ph.D. (LaRC).** Providing needed expertise in the area of high performance polymers for space applications, including environmentally durable

and high temperature polymers. Also brings experience in program formulation and planning.

- **Surendra N. Singhal, Ph.D. (MSFC).** Providing needed expertise in the areas of structures and materials engineering and technology for energy and high temperature programs. Also, brings background in CRAI road map development.
- **Billy Kauffman, Ph.D. (MSFC).** Providing needed expertise in the area of space environments and effects.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Judith Watson (LaRC).** Providing needed expertise in the areas of large space structural concepts (and their testing), including aeroshells, reflector systems, platforms, and others. Brings experience in assembly test bed validation, as well as structural property validation. Also, brings background in exploration concepts analysis, and experience in diverse advanced concepts studies. Provides cross-pollination to the Advanced Space Operations element program. Cross-pollination from the Advanced Space Platforms and Systems Program.

Ex Officio Team Members who will provide Enterprise Coordination

As appropriate, individual(s) may be named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Mike Wargo (Biological and Physical Research Enterprise).** Providing needed coordination related to advanced materials, space environments and effects.

I.1.3 Members of the ASTP Communications, Computing, Electronics & Imaging (CCEI) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Barbara Wilson, Ph.D. (Acting³²).**

Center Team Members

- **Bryan Biegel (ARC).** Providing needed expertise in the area of high end computing.

³² Dr. Wilson is a former JPL Chief Technologist, and former Director of the JPL Center for Space Microelectronics. (IPA paperwork in process.)

- **Kul Bhasin, Ph.D. (GRC).** Providing needed expertise in the area of space communications. (Served as the manager for Space Communications in the former CICT program.)
- **Pete Shu (GSFC).** Providing need subject matter expertise in visible and IR imaging sensors. Extensive experience in developing sensors for Code S and Code Y missions. Also brings line management experience as head of Detector Systems Branch.
- **Robert Ferraro, Ph.D. (JPL).** Providing needed expertise in the areas of parallel and distributed computing systems technologies, including the adaptation of COTS-based computers for spacecraft data processing, as well as high-end computing. Also, brings experience in technology flight experiments. Cross-pollinating to the TMP Advanced Space Systems and Platforms Element Program. Coordinating as 'rep' of Office of Earth Science for this Element Program.
- **Elizabeth Kolawa, Ph.D. (JPL).** Providing needed expertise in R&D of advanced electronic devices, electronic packaging, thin film materials, miniaturization and integration of electronics systems and sensors technologies.
- **Jeffrey Herath (LaRC).** Providing needed expertise in the areas of new approaches and technologies for space electronics, including novel concepts such as modular space systems. Brings broad experience in program formulation, planning and advocacy; also brings entrepreneurial industry experience.
- **William T. Powers (MSFC).** Providing needed expertise in the area of advanced avionics sensors, including temperature, pressure, force, strain, position and motion. Also brings experience in test beds and demonstrations such as the DC-X project.
- **Keith Williams (JSC).** Providing needed expertise in the area of communications of human space missions.
- **Kenneth Perko (GSFC).** Providing needed expertise in the area of advanced avionics sensors, including temperature, pressure, force, strain, position and motion. Also brings experience in test beds and demonstrations such as the DC-X project.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Robert Ferraro, Ph.D. (JPL for Code Y).** Coordinating with TMP ASPS.

Ex Officio Team Members who will provide Enterprise Coordination

The following individual(s) is/are named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Robert Ferraro, Ph.D. (JPL for Code Y).** Coordinating with Code Y regarding this element.
- **Darrell Jan (JPL, for Code U).** For coordination of advanced sensors technology needs and programs, applications of MEMS.
- **Gregory Dees (HQ for Code U).** Coordinating with Code U Space Product Development.
- **Karen Moe (GSFC for Code Y).** Coordinating with Code Y Earth Science Technology Program.

I.1.4 Members of the ASTP Software, Intelligent Systems & Modeling (SISM) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Butler Hine, Ph.D. (OExS; on Detail from ARC).**

Center Team Members

- **Mike Shafto, Ph.D. (ARC).** Providing needed expertise in the areas of human centered computing and intelligent systems.
- **Jimi Crawford, Ph.D. (ARC).** Providing needed expertise in the areas of autonomy, intelligent systems and robotics; also brings experience as manager of the CDS project in the former CICT program.
- **Claudia Meyer (GRC).** Providing needed expertise in the areas of intelligent systems R&D as applied to space transportation systems, IVHM and software V&V; also brings considerable aerospace industry experience. (Manager of the two space transportation related URETIs.)
- **Richard J. Doyle, Ph.D. (JPL).** Providing needed expertise in the areas of space mission information technologies, software systems, and intelligent systems/autonomy. Also brings experience in flight project support, and relevant research organization line management.
- **Christopher Culbert (JSC).** Providing needed expertise in the areas of automation, robotics and simulation; including planning and test bed validation of concepts for human and robotic cooperative activities. Also brings Mission Control Center experience. Cross-pollinate with TMP Advanced Space Operations Program.
- **Sharon Graves (LaRC).** Providing needed expertise in the areas of intelligent and evolvable systems, including development of embedded/small computer systems to enable in situ reconfigurable space systems.

- **Luis Trevino, Ph.D. (MSFC).** Providing needed expertise in the areas of avionics and flight software and computing technologies—particularly related to rocket engine control. He also brings experience in test beds and testing for various rocket propulsion development programs.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Mark Shirley, Ph.D. (ARC).** Providing needed expertise in the areas of information technology and model-based reasoning; served as the chief technologist for the former ECS (engineering for complex systems) program. Cross-pollinated from the Advanced Studies, Concepts and Tools Element Program.

Ex Officio Team Members who will provide Enterprise Coordination

As appropriate, individual(s) may be named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Karen Moe (GSFC-Earth Science Technology Office for Code Y).** For the more near term needs and developments associated with Earth Science Enterprise software and intelligent systems technology requirements.

I.1.5 Members of the ASTP Power, Propulsion and Chemical Systems (PPCS) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Christopher Moore, Ph.D. (OExS).**

Center Team Members

- **Dave Hoffman (GRC).** Providing needed expertise in the areas of power and propulsion related systems analysis, and R&D in power and propulsion. (Project Manager for the former MSM Energetics Project.) Also brings considerable international coordination and ISS project experience.
- **Ted Swanson (GSFC).** Providing needed expertise in the areas of thermal control in general and heat pipes / two-phase thermal control, in particular. Also brings experience as former a former sub-topic manager in the SBIR program.
- **James E. Polk, Ph.D. (JPL).** Providing needed expertise in a wide range of advanced electric and electromagnetic propulsion technologies, including ion engines, Hall thrusters, and others. Brings experience related to international

collaboration, as well as facilities planning and development related to electric propulsion technology testing.

- **Gerald B. Sanders (JSC).** Providing needed expertise in the areas of advanced chemical propulsion, energy storage and power management, in situ resource utilization, and others areas. Also brings experience in related technology flight experiments, as well as related to major flight subsystems of the Space Shuttle. Cross-pollination with the Lunar and Planetary Surface Operations element program planning.
- **William (Bill) E. Larson (KSC).** Providing needed expertise in the areas of Mars atmospheric in situ resource utilization, human exploration applications studies, and related consumables planning. Brings experience in Space Shuttle and International Space Station utilization.
- **Leonard Weinstein (LaRC).** Providing needed expertise in 'innovative thinking' as well as the areas of measurement techniques, as a well as a range of novel power and propulsion concepts.
- **John Cole (MSFC).** Providing needed expertise in the diverse areas of advanced space propulsion research.

Team Members who will provide H&RT Cross-Pollination

As appropriate, individual(s) will be named to provide needed coordination with other H&RT Element Program Teams:

- **TBDName (TBDCenter).** Providing needed expertise in the areas of TBD, TBD and TBD.

Ex Officio Team Members who will provide Enterprise Coordination

As appropriate, individual(s) may be named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Brad Carpenter (Biological and Physical Research Enterprise).** Providing needed coordination in the areas of thermal-, electrical- and chemistry- based processing of materials.

2.0 Technology Maturation Program (TMP)

The following are the members of the overall formulation team for the Technology Maturation Program. The critical roles to be performed by this team include: (a) developing an approach for how the various element programs within TMP will interact with one another, with the ITTP and with the Advanced Space Technology Program; (b) serving as knowledgeable ‘traffic cops’ in reviewing the element program plans as they emerge, and (c) supporting the development of a draft Technology Maturation Program Plan.

This set of names is based on the working inputs received as of 16-22 April 2004; updates and revisions are expected as additional selections are made and/or updates to initial center candidate lists are received.

2.0.1 Members of the TMP Overall Formulation Team

NASA HQ Lead

- **John C. Mankins (OExS).**

NASA HQ Team Members (Element Program Managers)

- **Nantel Suzuki (OExS).**
- **Robert Wegeng (OExS; on IPA from Batelle).**
- **Carlos Campos (OExS).**

Center Team Members

- **Dan Rasky, Ph.D. (ARC).** Providing a broad technology background and needed expertise in entry systems research and development, and ultra-high temperature ceramics. Also brings related industry research. Coordination with HESS.
- **Tony Whitmore (DFRC).** Providing needed expertise in concerning technology integration and maturation challenges faced in an aeronautics research and development environment.
- **Patrick George (GRC).** Providing needed expertise in the areas of ISS power systems, NASA-ESA collaboration and space solar power R&D. Also serves as an SBIR/STTR subtopic manager.
- **Maria So (GSFC).** Providing needed expertise in the areas of in space mission systems engineering, technology development planning and management, and technology database management. Current manager of the NASA Technology Inventory system. Cross pollinate with the Advanced Space Technology Program overall formulation team.
- **Jack Stocky (JPL).** Providing needed expertise in the areas of advanced power and propulsion, technology flight demonstrations, and technology

- forecasting/assessment/planning for space science missions; also brings both program and line management experience.
- **Brenda Ward (JSC).** Providing needed expertise in the areas of exploration studies and planning, technology demonstration planning and coordination; also brings both program and line management experience.
 - **Jeryl R. Hill (LaRC).** Providing needed expertise in the areas of technology development, demonstration and project management; also brings past experience as deputy director of systems engineering with the Space Station program.
 - **Joe Howell (MSFC).** Providing needed expertise in the areas of advanced technology concepts studies, space solar power exploratory research and technology, and others. Brings line management experience related to advanced technology projects and program formulation.
 - **Robert Bruce (SSC).** Providing needed expertise in the areas of rocket propulsion technology testing and test facilities; providing coordination with aspects of the ITTP program.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Anthony R. Gross (ARC).** Providing needed expertise in the various areas related to human-centered computing and IVHM; bring experience as a Center SBIR POC. Coordination between TMP and ITTP.
- **Neville Marzwell, Ph.D. (JPL).** Providing needed expertise in the areas of advanced space systems concepts, modular systems, satellite servicing systems, robotics, advanced power systems, and other areas. Also brings experience in both industry and NASA (JPL) research activity planning and management. Cross-pollination with Advanced Studies, Concepts and Tools, Advanced Space Platforms and Systems.
- **Rita Willcoxon (KSC).** Providing needed expertise in the areas of advanced spaceport and range technology projects, payload planning and operations, R&D project formulation and advocacy, as well as Space Station utilization planning. Also brings line management experience. Cross pollinate with Advanced Space Operations Program.

Team Members who will provide Coordination Among Enterprises

The following individual(s) is/are named to provide needed coordination with other NASA Enterprises.

- **Lisa Guerra (Code U).** Providing needed coordination with exploration-supporting programs in the Office of Biological and Physical Research.
- **Janice Buckner (GSFC/Earth Science Technology Office (ESTO), representing Code Y).** Providing needed coordination between ESTO and technology maturation R&D needs, planning and programs.

The paragraphs that follow provide the names of are the members of the several element program formulation teams within the Technology Maturation Program.

I.2.1 Members of the TMP High Energy Space Systems (HESS) Technology Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Nantel Suzuki (OExS).**

Center Team Members

- **Dan Rasky, Ph.D. (ARC).** Providing a broad technology background and needed expertise in entry systems research and development, and ultra-high temperature ceramics. Also brings related industry research. Coordination with TMP overall planning.
- **Tony Whitmore (DFRC).** Providing needed expertise in concerning technology integration and maturation challenges faced in an aeronautics research and development environment.
- **Jim Soeder (GRC).** Providing needed expertise in the areas of advanced power management and distribution (PMAD) technologies, energy storage and space station power systems.
- **Jim Dudenhoefer (GRC).** Providing needed expertise in the related to advanced power technologies; special experience related to DOD Advanced Concepts Technology Demonstration (ACTD) projects and NASA-DOD collaboration related to space power.
- **Robert F. Boyle (GSFC).** Providing needed expertise in the areas of cryogenic systems and cryocoolers; as well as a background in flight systems development and related technology flight experimentation.
- **Claude Graves (JSC).** Providing needed expertise in the areas of aeroassist technology development, including thermal protection systems, GN&C, configuration definition, and others areas. Brings broad, Agency-level experience,
- **Robert G. Johnson (KSC).** Providing needed expertise in the areas of cryogenic propellant engineering and technology development and testing. Also brings SBIR sub-topic management experience, and background with the USAF, as well as the Space Shuttle program.

- **Tim Collins (LaRC).** Providing needed expertise in the areas related to modular systems assembly, along with expertise in high-temperature composite materials and adhesives (e.g., for use in aerocapture systems).
- **John Fikes (MSFC).** Providing needed expertise in the areas of advanced concepts studies, including cryogenic propellant depots, wireless power transmission, and others. Also brings relevant SBIR subtopic leadership experience.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **James E. Polk, Ph.D. (JPL).** Providing needed expertise in a wide range of advanced electric and electromagnetic propulsion technologies, including ion engines, Hall thrusters, and others. Brings experience related to international collaboration, as well as facilities planning and development related to electric propulsion technology testing. Cross pollination with the ASTP Power, Propulsion and Chemical Systems Element Program.

Ex Officio Team Members who will provide Enterprise Coordination

As appropriate, individual(s) may be named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **TBDName (Enterprise).** Providing needed expertise in the areas of TBD, TBD and TBD.

I.2.2 Members of the TMP Advanced Space Platforms & Systems (ASPS) Technology Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Robert Wegeng (OExS; on IPA from Batelle).**

Center Team Members

- **Serdar Uckun, M.D. (ARC).** Providing needed expertise in the areas of integrated vehicle health management (IVHM).
- **Jaime Esper (GSFC).** Providing needed expertise in the areas of advanced space systems concepts, including modular, reconfigurable and rapid-response systems. Also provides an important linkage to the Air Force Research Laboratory (AFRL) in Albuquerque where he is on detail as liaison to the DOD Space Test Program. He will also cross-pollinate with the In-Space Technology Experiments Program.

- **Neville Marzwell, Ph.D. (JPL).** Providing needed expertise in the areas of advanced space systems concepts, modular systems, satellite servicing systems, robotics, advanced power systems, and other areas. Also brings experience in both industry and NASA (JPL) research activity planning and management. Cross-pollination with Advanced Studies, Concepts and Tools.
- **Elena M. Huffstetler (JSC).** Providing needed expertise in the areas of project planning and management for advanced technology projects, flight experiment project management, and strategic planning. Also brings experience in Space Shuttle flight integration (and related management).
- **Judith Watson (LaRC).** Providing needed expertise in the areas of large space structural concepts (and their testing), including aeroshells, reflector systems, platforms, and others. Brings experience in assembly test bed validation, as well as structural property validation. Also, brings background in exploration concepts analysis, and experience in diverse advanced concepts studies. Provides cross-pollination to the Advanced Space Operations element program. Coordinate with Advanced Materials and Structural Concepts.
- **Jon B. Holladay (MSFC).** Providing needed expertise in the areas of concept studies through development, design, acceptance, operations and sustaining engineering for large space systems and platforms. Brings experience related to ISS utilization. Provides cross-pollination to the InSTEP element program.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Anthony R. Gross (ARC).** Providing needed expertise in the various areas related to human-centered computing and IVHM; bring experience as a Center SBIR POC. Coordination with TMP, ITTP.
- **Robert Ferraro, Ph.D. (JPL).** Providing needed expertise in the areas of parallel and distributed computing systems technologies, including the adaptation of COTS-based computers for spacecraft data processing, as well as high-end computing. Also, brings experience in technology flight experiments. Providing coordination with the ASTP Communications, Computing, Electronics and Imaging Element Program.
- **Lara E. Kearney (JSC).** Providing needed expertise in the areas of Extravehicular Activity (EVA) technology planning and development, including related systems (such as tools, crew aids, mobility systems and airlocks). Also brings related industry experience. Coordinating with Advanced Space Operations.

Ex Officio Team Members who will provide Enterprise Coordination

As appropriate, individual(s) may be named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Jitendra Joshi (Code U).** Providing needed coordination with key activities in Code U related to robust and reconfigurable habitation systems, integrated system health management, and related topics.
- **Jim Breckinridge (Code S).** Providing needed coordination with key activities in Code S related to large space platforms (with particular emphasis on large space structural systems associated with large optical systems)

I.2.3 Members of the TMP Advanced Space Operations (ASO) Technology Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Nantel Suzuki (OExS).**

Center Team Members

- **Mary K. Kaiser (ARC).** Providing needed expertise in the area of human-machine interfaces, including advanced visual displays for vehicular control and teleoperations.
- **Rud Moe (GSFC).** Providing needed expertise in the areas of tele-robotics flight demonstration planning, Hubble Space Telescope Servicing, and planning for future in space assembly and construction. Also brings deep experience in Space Shuttle servicing planning and missions.
- **Matt Barry (JPL).** Providing needed expertise in the areas of intelligent systems technology, especially real-time mission-control and advanced on-board and ground training systems and environments. Also brings Space Shuttle mission operations Experience and related industry experience.
- **Brian Wilcox (JPL).** Providing needed expertise in the areas of advanced robotic systems concepts research, development and demonstration, including areas such as mobility, manipulation, sensing and perception, planning and reasoning and systems engineering. Also brings experience in line management related to rapid robotic vehicle development. Cross-pollination with the Lunar and Planetary Surface Operations Program formulation team.
- **Lara E. Kearney (JSC).** Providing needed expertise in the areas of Extravehicular Activity (EVA) technology planning and development, including related systems (such as tools, crew aids, mobility systems and airlocks). Also brings related industry experience. Coordinating with Advanced Space Platforms and Systems.
- **Rita Willcoxon (KSC).** Providing needed expertise in the areas of advanced spaceport and range technology projects, payload planning and operations, R&D

project formulation and advocacy, as well as Space Station utilization planning. Also brings line management experience.

- **Billy Doggett (LaRC).** Providing needed expertise in assessing and attempting to optimize the human-robotic roles in performing future, large-scale in-space assembly and construction. Brings extensive background in Agency-level assessment, and program formulation.
- **David Stephenson (MSFC).** Providing needed expertise in the areas of advanced space transportation related technology, including technology assessments and planning (in areas such as rendezvous and docking).

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Christopher Culbert (JSC).** Providing needed expertise in the areas of automation, robotics and simulation; including planning and test bed validation of concepts for human and robotic cooperative activities. Also brings Mission Control Center experience. Cross-pollinate with Communications, Computing, Electronics and Imaging.
- **Judith Watson (LaRC).** Providing needed expertise in the areas of large space structural concepts (and their testing), including aerosheels, reflector systems, platforms, and others. Brings experience in assembly test bed validation, as well as structural property validation. Also, brings background in exploration concepts analysis, and experience in diverse advanced concepts studies. Provides cross-pollination with the Advanced Space Platforms and Systems element program.

Ex Officio Team Members who will provide Enterprise Coordination

As appropriate, individual(s) may be named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Brad Carpenter (Code U).** Providing needed coordination with the Technology Maturation Program in the area of extravehicular activity (EVA) systems.

I.2.4 Members of the TMP Lunar & Planetary Surface Operations (LPSO) Technology Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Robert Wegeng (OExS; on IPA from Batelle).**

Center Team Members

- **Marc Cohen (ARC).** Providing needed expertise in the areas of space architecture and innovative lunar and/or Mars outpost concepts, including mobile outposts; also brings background in integrating various disciplines/topics in surface systems studies.
- **Kurt R. Sacksteder (GRC).** Providing needed expertise in the area of partial gravity environment effects (Lunar and Mars) on combustion and chemically-reacting flows; also brings experience in ground experimentation and in flight experimentation on both Space Shuttle and MIR space station.
- **Tom Rivellini (JPL).** Providing needed expertise in the areas of planetary entry, descent and landing, including highly innovative systems concepts (e.g., the MER EDL system architecture. Also brings experience in the testing of novel technology concepts.
- **John Gruener (JSC).** Providing needed expertise in the areas of systems engineering studies and program planning related to human and robotic space exploration, exploration science strategies and science requirements associated with exploration, and supporting analyses, system engineering, and cost studies.
- **David Taylor (KSC).** Providing needed expertise in the areas of life cycle analysis studies and Mars ISRU technology demonstration projects planning. Also brings experience in payloads engineering for the Space Shuttle.
- **Charles R. Baugher (MSFC).** Providing needed expertise related to sample-type science operations – e.g., use of a glove box facility within the space station.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Brian Wilcox (JPL).** Providing needed expertise in the areas of advanced robotic systems concepts research, development and demonstration, including areas such as mobility, manipulation, sensing and perception, planning and reasoning and systems engineering. Also brings experience in line management related to rapid robotic vehicle development. Cross-pollination from the Advanced Space Operations Program formulation team.
- **Gerald B. Sanders (JSC).** Providing needed expertise in the areas of advanced chemical propulsion, energy storage and power management, in situ resource utilization, and others areas. Also brings experience in related technology flight experiments, as well as related to major flight subsystems of the Space Shuttle. Cross-pollination with the Power Propulsion and Chemical Systems element program planning within ASTP.

Ex Officio Team Members who will provide Enterprise Coordination

The following individual(s) is/are named as ‘ex officio’ team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **John Connolly (OExS/Project Constellation).** Providing needed expertise in the areas of lunar and planetary surface systems, human precursor mission planning, and planning for future exploration mission science goals.
- **John Emond (Code U).** Providing needed coordination in the areas of in situ resource utilization (ISRU) technology, systems and flight experiments.

I.2.5 Members of the TMP In-Space Technology Experiments Program (InSTEP) Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Carlos Campos (OExS).**

Center Team Members

- **Mark Murbach (ARC).** Providing needed expertise in the areas of sounding rocket flight experiments and advanced systems concepts.
- **Angel Otero (GRC).** Providing needed expertise in the area of leading flight experiments from Phase A through flight for both Shuttle and ISS based flight experiment (fluids and combustion related). Also brings current experience in managing project operations for various ongoing and former projects.
- **Artur Chmielewski (JPL).** Providing a strong background related to earlier technology flight experiment programs, as well as more recent experience in planning for technology testing under the Code S New Millennium program.
- **Al Conde (JSC).** Providing needed expertise in the areas of strategic technology assessment and planning, human exploration architecture assessments, and technology flight experiment definition and coordination. Also brings experience in payload integration for both the Space Shuttle and the ISS programs. Cross-pollination with the Advanced Space Technology Program overall planning team.
- **Bill Kinard (LaRC).** Providing needed expertise in the areas of technology flight experiments at the ISS (particularly through leadership of the MISSE technology flight experiment program; brings experience in working with DOD.
- **Connie Carrington, Ph.D. (MSFC).** Providing needed expertise in the areas of large structural systems dynamics and controls, advanced concepts studies and modeling, and technology flight experiment and demonstration definition studies and planning.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Jaime Esper (GSFC).** Providing needed expertise in the areas of advanced space systems concepts, including modular, reconfigurable and rapid-response systems. Also provides an important linkage to the Air Force Research Laboratory (AFRL) in Albuquerque where he is on detail as liaison to the DOD Space Test Program. He will cross-pollinate with the Advanced Space Platforms and Systems Program.
- **Jon B. Holladay (MSFC).** Providing needed expertise in the areas of concept studies through development, design, acceptance, operations and sustaining engineering for large space systems and platforms. Brings experience related to ISS utilization. Provides cross-pollination with the Advanced Space Platforms and Systems element program.

Ex Officio Team Members who will provide Enterprise Coordination

The following individual(s) is/are named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Alan Holt (Office of Space Flight/ISS @ JSC).** Providing needed expertise in the areas of ISS utilization and technology flight experiment definition and accommodations.
- **Mark Sistilli (Office of Biological and Physical Research).** Providing needed coordination related to potential synergy with OBPR's planned free flyer program interests.
- **Tim VanSant (Office of Space Science).** Providing needed coordination related to potential synergy with technology flight experiments.

I.3 Innovative Technology Transfer Partnerships (ITTP) Program

The following are the members of the overall formulation team for the Innovative Technology Transfer Partnerships Program. The critical roles to be performed by this team include: (a) developing an approach for how the various element programs within ITTP will interact with one another, with the ASTP and with the Technology Maturation Program; (b) serving as knowledgeable ‘traffic cops’ in reviewing the element program plans as they emerge, and (c) supporting the development of a draft ITTP Program Plan.

This initial set of names is based on the working inputs received as of 16-22 April 2004; updates and revisions are expected as additional selections are made and/or updates to initial center candidate lists are received.

I.3.0.1 Members of the Overall ITTP Program Formulation Planning Team

NASA HQ Lead

- **Benjamin Neumann (OExS).**

NASA HQ Team Members (Element Program Managers)

- **Jack Yadvish (OExS).**
- **Carl Ray (OExS).**

Center Team Members

- **Lisa Lockyer (ARC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Greg Poteat (DFRC).** Providing needed expertise in the areas of technology transfer and/or STTR program.
- **Robert Lawrence (GRC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Nona Minnifield-Cheeks (GSFC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Ken Wolfenbarger, Ph.D. (JPL).** Providing needed expertise in the areas of technology transfer, SBIR and STTR programs, and intellectual property (IP) management. Also brings a background in chemical engineering and industrial R&D management.
- **Charlene Gilbert (JSC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Bob Yang (LaRC).** Providing needed expertise in the area of technology transfer planning and programs.

- **Vernatto McMillan (MSFC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Robert Bruce (SSC).** Providing needed expertise in the area of technology transfer planning and programs.

Team Members who will provide H&RT Cross-Pollination

As appropriate, individual(s) will be named to provide needed coordination with other H&RT Element Program Teams:

- **TBDName (TBDCenter).** Providing needed expertise in the areas of TBD, TBD and TBD.

Ex Officio Team Members who will provide Enterprise Coordination

The following individual(s) is/are named as 'ex officio' team members to provide needed coordination with other NASA Enterprises and related planning activities:

- **Frank Schowengerdt (Office of Biological and Physical Research).** Providing needed coordination related to technology development partnerships.
- **Parminder Ghuman (GSFC/Earth Science Technology Office (ESTO), representing Code Y).** Providing needed coordination between ESTO and ITTP planning/programs.

The paragraphs that follow provide the names of the members of the several element program formulation teams within the Innovative Technology Transfer Partnerships Program.

I.3.1 Members of the ITTP Technology Transfer (TT) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Jack Yadvish (OExS).**

Center Team Members

- **Rich Pisarski (ARC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Roberta Ross (DFRC).** Providing needed expertise in the areas of technology transfer and/or SBIR/STTR programs.
- **Walter Kim (GRC).** Providing needed expertise in the area of technology transfer planning and programs.

- **Nona Minnifield-Cheeks (GSFC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Ken Wolfenbarger, Ph.D. (JPL).** Providing needed expertise in the areas of technology transfer, SBIR and STTR programs, and intellectual property (IP) management. Also brings a background in chemical engineering and industrial R&D management.
- **Jane Fox (JSC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Dave Makufka (KSC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Bob Yang (LaRC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Vernotto McMillan (MSFC).** Providing needed expertise in the area of technology transfer planning and programs.
- **Robert Bruce (SSC).** Providing needed expertise in the area of technology transfer planning and programs.

Team Members who will provide H&RT Cross-Pollination

As appropriate, individual(s) will be named to provide needed coordination with other H&RT Element Program Teams:

- **TBDName (TBDCenter).** Providing needed expertise in the areas of TBD, TBD and TBD.

I.3.2 Members of the ITTP Small Business Innovation Research (SBIR) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Carl Ray (OExS)**

NASA HQ Team Members

- **Paul Mexcur (SBIR/STTR Program Manager (at GSFC))**
- **Jan Kalshoven (HQ Program Office at GSFC)**
- **Robert Nelson (TBD)**
- **Janet Jew (TBD)**
- **Jonathan Root (HQ)**

Center Team Members

- **Rodney Bogue (DFRC).** Providing needed expertise in the areas of technology transfer and/or SBIR program.
- **Walter Kim (GRC).** Providing needed expertise in the areas of technology transfer and/or SBIR programs.
- **Engmin (Jim) Chern (GSFC).** Providing needed expertise in the SBIR and STTR programs, including program planning, topic and subtopic formulation, and proposal review and oversight.
- **Wayne Schober, Ph.D. (JPL).** Providing needed expertise in the areas of SBIR program direction and management; also brings experience in NASA cooperative projects with DOD (particularly the USAF).
- **Jane Fox (JSC).** Providing needed expertise in the areas of technology transfer and/or SBIR programs.
- **Chuck Griffin (KSC).** Providing needed expertise in the areas of technology transfer and/or SBIR programs.
- **Robert Yang (LaRC).** Providing needed expertise in the areas of technology transfer and/or SBIR programs.
- **Helen Stinson (MSFC).** Providing needed expertise in the areas of technology transfer and/or SBIR programs.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Anthony R. Gross (ARC).** Providing needed expertise in the various areas related to human-centered computing and IVHM; bringing experience as a Center SBIR POC. Coordination with TMP.
- **Carlos Campos (OExS).** Providing needed expertise related to the translation of SBIR projects to higher fidelity technology programs. Coordination with TMP/InSTEP.

Ex Officio Team Members who will provide Enterprise Coordination

The several Strategic Enterprise Representatives to the SBIR program will be invited to review/commend on the emerging SBIR Element Program Planning.

I.3.3 Members of the Small Business Technology Transfer (STTR) Program Formulation Team

The individuals identified as members of this Formulation Team will be responsible for the development of a draft Program Plan, in accordance with the standard H&RT Element Program Plan outline (provided separately).

NASA HQ Lead

- **Carl Ray (OExS)**

NASA HQ Team Members

- **Paul Mexcur (SBIR/STTR Program Manager (at GSFC))**
- **Jan Kalshoven (HQ Program Office at GSFC)**
- **Robert Nelson (TBD)**
- **Janet Jew (TBD)**
- **Jonathan Root (HQ)**

Center Team Members

- **Greg Poteat (DFRC)**. Providing needed expertise in the areas of technology transfer and/or STTR program.
- **Walter Kim (GRC)**. Providing needed expertise in the areas of technology transfer and/or STTR programs.
- **Engmin (Jim) Chern (GSFC)**. Providing needed expertise in the SBIR and STTR programs, including program planning, topic and subtopic formulation, and proposal review and oversight.
- **Wayne Schober, Ph.D. (JPL)**. Providing needed expertise in the areas of SBIR program direction and management; also brings experience in NASA cooperative projects with DOD (particularly the USAF).
- **Jane Fox (JSC)**. Providing needed expertise in the areas of technology transfer and/or STTR programs.
- **Chuck Griffin (KSC)**. Providing needed expertise in the areas of technology transfer and/or STTR programs.
- **Robert Yang (LaRC)**. Providing needed expertise in the areas of technology transfer and/or STTR programs.
- **Helen Stinson (MSFC)**. Providing needed expertise in the areas of technology transfer and/or STTR programs.

Team Members who will provide H&RT Cross-Pollination

The following individual(s) is/are named to provide needed coordination with other H&RT Element Program Teams:

- **Anthony R. Gross (ARC)**. Providing needed expertise in the various areas related to human-centered computing and IVHM; bringing experience as a Center SBIR POC. Coordination with TMP.

Ex Officio Team Members who will provide Enterprise Coordination

The several Strategic Enterprise Representatives to the STTR program will be invited to review/commend on the emerging STTR Element Program Planning.

Appendix J

Human and Robotic Technology Working Forecast of Future Space Exploration Events and Activities Version 1.0 - 14 May 2004

The following is a working forecast of future events and activities associated with achieving the U.S. National Vision for Space Exploration. This forecast is not intended as a statement of official U.S. government policy (except where noted explicitly); rather, it is intended to guide near-term decisions concerning investment opportunities and requirements.

Five types of events and activities are identified: (1) scientific research and knowledge acquisition activities (designated as “SRK”); (2) technology research and development activities (“R&D”); (3) system development activities (“SD”); (4) major infrastructure events (“MI”); (5) exploration mission events and activities (“EM”); and, (6) Major Policy Events (MPE). Where appropriate, system development activities and exploration mission events will be designated as part of “Spiral 1”, “Spiral 2”, etc., as consistent with planning within NASA and the Exploration Systems Enterprise.

This working forecast of future space exploration events and activities is divided into several timeframes; these include:

- FY 2004 – the current fiscal year.
- FY 2005 to 2009 – the first five years of implementation of the National Vision for Space Exploration, including major technology, development and scientific research objectives.
- FY 2010 to 2019 – the next ten years of implementation of the Vision, including major infrastructure events, systems developments, scientific research accomplishments, and validation/invalidation of important systems-of-systems level innovative concepts and technologies.
- FY 2019-20 to 2029-30 – the ten years of human and robotic mission activities that will be centered around the human return to the Moon, and establishing the major systems and concepts of operations that will enable ambitious human/robotic exploration activities across the Solar System, in future years.
- Post-FY 2030 – the farthest forecast timeframe, including a projected timeframe for initial human explorers to join the ongoing robotic exploration of Mars.

In general, the nearer term forecast provides greater detail and includes explicit major events that are called for in the National Vision for Space Exploration; the farther term forecast provides less detail and includes notional extrapolation of future “spirals” and events that are derived from the National Vision, but are not explicitly required by it.

FY 2004

The following is a summation of events and activities during FY 2004, including both past and planned events (as of May 2004).

MPE: Announcement of the new U.S. National Vision for Space Exploration (14 January 2004).

MPE: Results of the Presidential Commission on Space Exploration (June 2004).

R&D: Reformulation of the several programs within the Human and Robotic Technology (H&RT) Theme, including the development of new program plans, as well as intramural and extramural competitions – beginning the **first cycle** of innovation for H&RT.

SD-Spiral 1: Broadly-based Request for Information (RFI) in support of Requirements definition processes and Project Constellation planning.

SD-Spiral 1: Concept Exploration and Refinement Broad Area Announcement (BAA), initiating industry participating in the process of requirements definition and studies to define options for Spiral 1 developments, including the Crew Exploration Vehicle (CEV) and supporting systems.

FY 2005 to 2009

The following is a summation of planned and projected events and activities during FY 2005-2009, including key targeted events in response to the National Vision

FY 2005

MPE: First full year of NASA programs in support of the U.S. National Vision for Space Exploration.

R&D: Implementation of “Pilot Project” phase for new projects within H&RT programs, ASTP and TMP, (initiated following FY 2004 intramural and extramural competitions); followed by Termination Reviews (Summer 2005).

R&D: Implementation of “gap-filling” BAA for Technology Maturation Program (Winter/Spring 2005), in response to technology gaps identified through Concept Exploration and Refinement industry studies; initiation of gap-filling projects in late 2005.

SD-Spiral 1: Request for Proposals (RFP) for implementation of Crew Exploration Vehicle (CEV) competitive demonstration flight(s) in 2008.

FY 2006

R&D: First year of implementation of “Phase 2” for projects within H&RT programs, ASTP and TMP (initiated following FY 2004 intramural and extramural competitions), as well as ‘gap-filling’ projects within TMP (initiated during 2005) followed by Continuation Reviews (Summer 2006).

SD-Spiral 1: Potential for initial down-selection associated with implementation of the Crew Exploration Vehicle (CEV) competitive demonstration flight(s) by 2008.

FY 2007

R&D: Continuing implementation of Phase 2 for projects within H&RT programs, ASTP and TMP, which were initiated following FY 2004 intramural and extramural competitions (these project efforts comprise the first ‘cycle of innovation’ within H&RT in support of Spiral 1, Spiral 2 and other exploration technology needs.

R&D: Beginning of the **second cycle** of innovation, with the reformulation of the several programs within the Human and Robotic Technology (H&RT) Theme, including the development of revised program plans, as well as intramural and extramural competitions for technology developments to be completed by 2011. Particular emphasis will be placed on ‘systems-of-systems’ level innovations related to Project Constellation **Spiral 2** (the human lunar return) to be validated/invalidated by 2011.

FY 2008

SRF: U.S. robotic lunar orbiter mission launched, acquiring diverse new knowledge concerning the lunar surface and space environments to inform future R&D and SD decisions; this is an event to support the National Vision.

R&D: Completion of the **first cycle** of innovation for Human and Robotic Technology (H&RT); all technology project results reviewed and transitioned to ongoing exploration system development efforts and to inform future H&RT investment decisions. Deliverables related to systems-of-systems level innovations for **Spiral 2**, and sub-system level ‘gap-filling’ technology developments in support of **Spiral 1**.

R&D: Implementation of “Pilot Project” phase for new projects within H&RT programs, ASTP and TMP, that were initiated as a result of the FY 2007 intramural and extramural competitions; followed by Termination Reviews (Summer 2008).

SD-Spiral 1: Crew Exploration Vehicle (CEV) development program “fly-off” of alternative vehicle concepts; this is an event to support the National Vision.

FY 2009

SRF: U.S. robotic lunar lander mission launched, acquiring new knowledge concerning the lunar surface and lunar surface environments to inform future R&D and SD decisions; this is an event to support the National Vision.

FY 2010 to 2019

The following is a forecast of events that would occur during the years preceding the initial human lunar return (HLR), targeted to occur no later than 2020 within the National Vision for Space Exploration. Several of these forecast events and activities are part of national policy. This forecast is intended only to guide decisions regarding H&RT investments.

~FY 2010

MI: Final Flight(s) of the Space Shuttle projected to occur; this is an event required to support the National Vision.

R&D: Beginning of the **third cycle** of innovation with the reformulation of several programs within the H&RT Theme, including ASTP and TMP, with development of revised program plans, as well as intramural and extramural competitions for technology developments to be completed by 2017. Particular emphasis will be placed on ‘systems-of-systems’ level innovations related to a possible Project Constellation **Spiral 3** (concerning the use of the Moon as a test bed for Mars).³³

FY 2011

EM-Spiral 1: First flight of the Crew Exploration Vehicle (CEV), without crew; a system within Project Constellation; this is an event required to support the National Vision.

R&D: Completion of the **second** cycle of innovation for Human and Robotic Technology (H&RT); all technology project results reviewed and transitioned to ongoing exploration system development efforts and to inform future H&RT investment decisions; particular emphasis on informing ‘systems-of-systems’ level decisions concerning the planned (NLT) 2020 human lunar return (HLR) as a result of Project Constellation **Spiral 2**.

FY 2013

R&D: Beginning of the **fourth cycle** of innovation with the reformulation of several programs within the H&RT Theme, including ASTP and TMP, with development of revised program plans, as well as intramural and extramural competitions for technology developments to be completed by 2020. Particular emphasis will be placed on ‘systems-of-systems’ level innovations related to projected Project Constellation **Spiral 4**³⁴ (related to deployment of a launch vehicle for use in Mars exploration, as well as options for expanded activities on the Moon, including lunar in situ resource utilization), as well as on sub-system level technology gap-filling activities for **Spiral 3**.

FY 2014

EM - Spiral 1: First flight (with crew) of the CEV with crew, plus supporting systems for operations in low Earth orbit (LEO); this is an event required to support the National Vision.

R&D: Completion of the **third** cycle of innovation for H&RT; all technology project results reviewed and transitioned to ongoing exploration system development efforts and

³³ This use of “Spiral 3” is not an official OExS plan, nor is a specific part of National policy; it is intended to guide/inform H&RT planning associated with longer term exploration events that might follow the initial human return to the Moon by no later than 2020.

³⁴ This use of “Spiral 4” is not an official OExS plan, nor is a specific part of National policy; it is intended to guide/inform H&RT planning associated with longer term exploration events that might follow the use of the Moon as a test bed for Mars, by no later than ~2023.

to inform future H&RT investment decisions; with particular emphasis on (a) technology that will have a sub-system level impact on decisions for the HLR mission (to be implemented NLT 2020) as a result of Project Constellation **Spiral 2**; and (b) technology that will have a systems-of-systems level impact on missions to use the Moon as a test bed for Mars (c. 2023+) as result of a possible Project Constellation **Spiral 3**.

~FY 2015

EM: 2015 is the nominal timeframe for an initial mission using nuclear electric power and propulsion resulting from Project Prometheus within the H&RT Theme; the ‘Jupiter Icy Moons Orbiter (JIMO) mission.

~FY 2016

R&D: Beginning of the fifth cycle of innovation with the reformulation of several programs within the H&RT Theme, including ASTP and TMP, with development of revised program plans, as well as intramural and extramural competitions for technology developments to be completed by 2020. Particular emphasis will be placed on ‘systems-of-systems’ level innovations related to a possible Project Constellation Spiral 5 (notionally, development and deployment of an interplanetary transportation vehicle and support infrastructure that could take humans to Mars and beyond).³⁵ A key dependency is the need for results from humans-in-space research on the ISS in finalizing these technology plans (completed by the 2016-2017 timeframe; see below).

~FY 2016-17

SRK: Completion of human subject research on the International Space Station (ISS) to inform microgravity effects-related and other decisions regarding approaches/technologies needed to enable safe, affordable and effective human exploration beyond the Moon, including the human missions to Mars.

MI: “Transition of the ISS” to non-NASA funding and associated reformulation of Agency budgets to support strengthened investment in new systems developments (including the human lunar return by no later than 2020); this is an event anticipated in budget documents accompanying the National Vision.

~FY 2016-2019

EM (projected): Notional timeframe for implementation of one or more Mars Sample Return (MSR) missions to provide key ‘ground-truth’ data from terrestrial laboratories concerning both the chemistry of the Martian environment as well as planetary protection issues, in support of later decisions concerning human astronauts joining the ongoing exploration of Mars.

³⁵ This use of “Spiral 5” is not an official OExS plan, nor is a specific part of National policy; it is intended to guide/inform H&RT planning associated with longer term exploration events that might follow evolutionary development of lunar surface systems c. ~2026+.

~FY 2017

R&D: Completion of the **fourth cycle** of innovation for H&RT; all technology project results reviewed and transitioned to ongoing exploration system development efforts and to inform future H&RT investment decisions; with particular emphasis on (a) technology that will have a sub-system level impact on missions to use the Moon as a test bed for Mars (c. 2023+) as result of a possible Project Constellation **Spiral 3**; and, (b) technology that will have a systems-of-systems level impact on missions to evolutionary Lunar systems, and potential development of new Earth-to-orbit (ETO) systems for later human missions to Mars (c. 2026+ for IOC of a new ETO system), as result of a potential Project Constellation **Spiral 4**.

~FY 2017-2019

EM (projected): Notional timeframe for implementation of the Terrestrial Planet Finder (TPF) mission, which is a part of the Search for Origins program, and an important mission component of the National Vision for Space Exploration.

~FY 2019

R&D: Beginning of the sixth cycle of innovation with the reformulation of several programs within the H&RT Theme, including ASTP and TMP, with development of revised program plans, as well as intramural and extramural competitions for technology developments to be completed by 2023. Particular emphasis will be placed on ‘systems-of-systems’ level innovations related to Project Constellation Spiral 6 (notionally, deployment of transformational new systems for surface access and operations to enable human excursions to the surface of Mars).³⁶ A key dependency is the need for results from humans-in-space research on the ISS in finalizing these technology plans (completed by the 2016-2017 timeframe).

FY 2019-20 to 2029-30

The following is a forecast of events that may follow on the initial human lunar return (HLR), targeted to occur no later than 2020 within the National Vision for Space Exploration. Except for the HLR by no later than 2020, none of these forecast events and activities is part of national policy; rather, this forecast is intended only to guide decisions regarding H&RT investments.

FY 2019-2020

EM-Spiral 2: Human Lunar Return (HLR), using the CEV plus additional supporting systems for operations beyond LEO, including access to the lunar surface; this is an event required to support the National Vision.

³⁶ This use of “Spiral 6” is not an official OExS plan, nor is a specific part of National policy; it is intended to guide/inform H&RT planning associated with longer term exploration events that might follow the initial human return to the Moon by no later than 2020.

R&D: Completion of the **fifth cycle** of innovation for H&RT; all technology project results reviewed and transitioned to ongoing exploration system development efforts and to inform future H&RT investment decisions; with particular emphasis on (a) technology that will have a sub-system level impact on missions to evolutionary developments on the Moon or on development of a new launch vehicle for later human missions to Mars (c. 2026+) as result of a possible Project Constellation **Spiral 4**; and, (b) technology that will have a systems-of-systems level impact on systems for human interplanetary transportation as result of a potential Project Constellation **Spiral 5**.

FY 2023

EM-Spiral 3 (projected): Beginning of the use of the Moon as a test bed for Mars; this is an event consistent with the National Vision.

~FY 2023-2026

EM (projected): Beginning of the Terrestrial Planet Imager (TPI) mission, a part of the Search for Origins program, and an important mission component of the National Vision for Space Exploration.

FY 2026

EM-Spiral 4 (projected): Evolutionary development of lunar surface activities, including expanded R&D and/or development of systems to support utilization of lunar surface resources; deployment and testing of new Earth to orbit (ETO) systems to support future human exploration beyond the Moon; including human missions to Mars.

~FY 2029

EM-Spiral 5 (projected): Initial operational capability (IOC) and first flight of new interplanetary transportation vehicles (ITVs) for future use in human Mars missions (may be robotic or with crew); establishment of new infrastructure and operations in Mars orbit. First use of new (if any) ETO transportation systems in support ITV launch and logistics.

FY 2030 and beyond

The following is a forecast of events in the far term that may follow planned events and activities during the 2020s. This forecast is intended only to guide decisions regarding H&RT investments.

~FY 2033+

EM-Spiral 6 (Projected): First Human Mission to Mars (HMM).

